The
ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XII No. 3. MARCH, 1951

UNIVERSITY OF MICHIGAN
APR 2 1951
ENGINEERING LIBRARY

Early attempts at using steam tractors to haul ploughing and cultivating machinery always failed. Even track-laying engines such as this 1857 Tuxford Boydell got hopelessly bogged because of their great weight. Nowadays, of course . . . ***MODERN ENGINEERS SPECIFY***

BOOTH BIRMINGHAM

DURALUMIN REGD. TRADE MARK

The Strong Light Aluminium Alloy

JAMES BOOTH & COMPANY LIMITED · ARGYLE STREET WORKS · BIRMINGHAM · 7

A blade for every purpose

'KERAUNOS' Super High Speed Steel Hacksaw Blades for handsawing hard and tough materials, including nickel chrome steels, stainless annealed tool steels; repetition production handsawing; all power sawing. Ensure high output at minimum cost.

'PAX' Tungsten Steel Blades for general shop work by skilled men.

'PAX FLEXTRA' Springback blades for semi-skilled operatives and for sawing where work cannot be held firmly.

'PAX FLEXIBLE' for use where saw is subject to rough handling.

'PAX DOUBLE EDGE' is the plumber's and electrician's blade. Used for cutting conduit and tubing.

THE SABEN RANGE

THE SABEN RANGE includes :— Precision - ground, hardened and tempered tool holder bits, brands; 'Saben Tenco' (10% Cobalt 22% Tungsten), 'Saben Wunda, (6% Cobalt 22% Tungsten), 'Saben Extra' (18% Tungsten); files and Engineers' small tools: high speed and carbon twist drills.

SABEN PRODUCTS

Ask your trade suppliers for 'KERAUNOS' and 'PAX' blades and other SABEN tools.

SANDERSON BROTHERS AND NEWBOULD LIMITED

ATTERCLIFFE STEELWORKS, SHEFFIELD

Steel and Saw Makers for 170 years

"Cronite"

REGD. TRADE MARK

now

WRITE FOR A NEW BOOKLET

The HIGH TEMPERATURE ALLOY

SALT, LEAD AND CYANIDE VESSELS
CARBURIZING BOXES AND POTS
ROTARY RETORTS & PROPELLING WORMS
FURNACE HEARTHS AND FITTINGS
ENAMELLING PERRITS AND SUPPORTS
GLASS-BLOWING NOZZLES
PYROMETER PROTECTION SHEATHS

CASTINGS FOR USE AT 700°/1200° C.

The **CRONITE FOUNDRY Co. LTD**

LAWRENCE RD · TOTTENHAM · LONDON N15

PHONE · STAMFORD HILL 4237

CONTENTS

	Page
The Blue Pages	71
Editorial	75
Improving Internal Combustion Engine Efficiency by Means of Exhaust Gas Utilisation	76
Freeze Drying	79
An Unusual Case of Critical Speeds in Centrifugal Pumps	80
Maximum Heat Transfer to Boiling Water at High Pressures	81
Design and Calculation of Spot-Welded Joints under Static Shear Loads	85
The Compressibility of Iron Powder	89
Further Developments of the NBS Magnetic Fluid Clutch	91
Measurement of Pressure by Means of Metallic Test-Pieces	94
Electrical Analogy Determination of Torsional Vibration Frequencies of Shaft Systems	96
New Materials, Processes and Equipment	99
Classified Abstracts	101
News of the Month	103

The ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XII. No. 3 MARCH, 1951

EDITORIAL AND ADVERTISING OFFICES:

GREAT BRITAIN
120 Wigmore Street, London, W.1.
Telephone: WELbeck 9357 & 6263

U.S.A.
366 Madison Avenue, New York 17, N.Y.
Telephone: MUrray Hill 2-8865

FRANCE
93 Champs-Élysées Paris, (8e)
Telephone: Élysées 09-03

Annual Subscription Rates:
£2 2s. 0d. in the Sterling area, $7.50 in the Dollar area.

Printed in Gt. Britain by ROBERT STOCKWELL LTD., 5-7 Baden Place, London, S.E.1, and published monthly by the proprietors, ENGINEERS' DIGEST LTD., 120 Wigmore Street, London, W.1.

PITMAN

Books for Engineers and Students

The Practical Engineer Pocket Book, 1951

Edited by N. P. W. MOORE, B.Sc., A.C.G.I., D.I.C., A.M.Inst.F. A famous pocket book, now in its 63rd year of publication. With Technical Dictionaries in German, French and Spanish. Over 750 pages. 8/6 net.

Telephony (2 vols.)

By J. ATKINSON, A.M.I.E.E. With over 1500 illustrations. Vol. I (General Principles and Manual Exchange Systems) 35/- net. Vol. II (Automatic Exchange Systems) 50/- net.

Calculations from Drawings

By F. HOLLIDAY, B.Sc., A.F.R.Ae.S. A book of graded examples, derived from up-to-date engineering practice, for bench fitters, toolmakers, etc. With outline solutions and answers. 7/6 net.

A Pocket-Book for Miners and Metallurgists

Compiled by FREDERICK DANVERS POWER. Describes the techniques used in the industry and includes all the fundamental data required by mining surveyors and engineers. 83 illustrations. 25/- net.

Diesel Fault Tracing, Maintenance and Repair

By STATON ABBEY. Deals with all types of high-speed diesel engines, and includes ten systematic diagnosis charts. 118 illustrations. 15/- net.

Cellulose Spraying

By JOHN HOWELL OUSBEY. A useful handbook on finishing and refinishing with cellulose and synthetics. It covers a wide field, including faults and their remedies, and gives helpful technical information. 16 illustrations. 8/6 net.

Transients in Electric Circuits

Using the Heaviside Operational Calculus. By W. B. COULTHARD, B.Sc. (Eng.), A.M.I.E.E., M.A.I.E.E. Illustrated. 21/- net.

Air Systems For Aircraft

By C. A. H. POLLITT, M.I.E.D., A.M.I.Ae.S. A detailed guide to modern pneumatic equipment used in operating ancillary services in civil and military aircraft. 95 illustrations. 25/- net.

Manual of Time and Motion Study

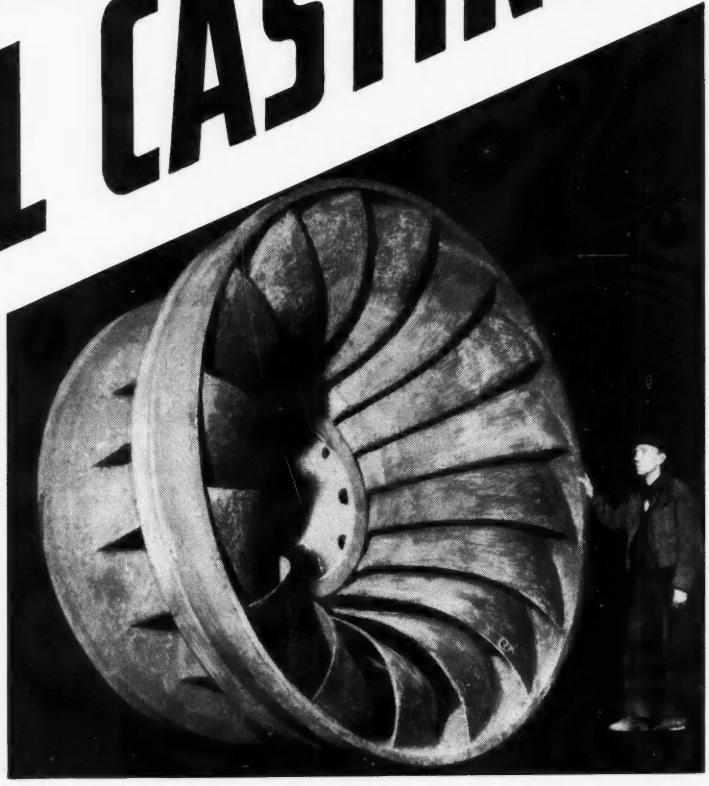
By JOHN W. HENDRY. A standard work on this subject by a well-known management expert. Third Edition. 15/- net.

The Nature of Management

Edited by H. R. LIGHT, B.Sc. (Lond.), F.C.I.S. A new book covering the syllabus for the "Nature of Management" paper in the Common Intermediate Examination in Management. 12/6 net.

SIR ISAAC PITMAN & SONS LTD., *Parker Street, Kingsway, London, W.C.2*

STEEL CASTINGS



In weights ranging from a few pounds up to 150 tons and embracing the requirements of almost all branches of industry.

May we have your enquiries ?

ENGLISH STEEL CORPORATION LTD

SHEFFIELD

THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *MOLYBDENUM PLATING*

It appears that considerable progress has been achieved, at least on the laboratory scale, in producing an adherent non-porous layer of molybdenum on other metals or alloys. In this process, a plating of molybdenum is obtained by the hydrogen reduction of molybdenum pentachloride vapour. Pressure of the vapour mixture has been found to have a strong influence on the properties of the resultant molybdenum plate. It is reported that a coarse-grained structure of optimum qualities could be produced at temperatures of about 1560° F and higher, and a total pressure below one inch of mercury. The intimate contact of the molybdenum coating with the parent metal was indicated by the absence of voids and inclusions at the interface and by inter-diffusion between the molybdenum and the parent metal. Adequate adhesion of molybdenum on steel was accomplished by first electrodepositing a layer of nickel on the steel before depositing the molybdenum from the pentachloride vapour. In this case, the inter-diffusion produced a solid solution with a gradual change in composition in depth. This forms an excellent bond between the nickel and the steel at the temperature used in depositing the molybdenum. The adhesion produced in this way was found to be much superior to that obtained without an intermediate layer of nickel.

● *RESIDUAL STRESSES IN MACHINED SURFACES*

In the machining of metals, extremely high residual stresses may be induced in the surface of the metal by the action of the cutting tool, even when light cuts are taken. A recent report draws attention to the fact that these stresses are generally tensile in the case of ductile materials, such as carbon steel, but are compressive in cast iron. It is further pointed out that the stresses are closely related to the work-hardening properties of the material and seem to be a function of the mechanical action of the tool, while they do not appear to depend much upon the thermal effect of the cutting; they increase with decreasing carbon content and with decreasing cutting speed. The stresses produced are invisible and their existence can be revealed only by the observation of their effects. It is important to note that the concentration and the magnitude of the machining stresses have considerable detrimental effects, such as warping. Also, a stress concentration in the surface of almost the same order of magnitude as the real tensile strength at breaking of the material obviously cannot be without other serious adverse effects upon the finished article. It lowers the resistance to wear and corrosion, and constitutes the unseen cause of failure from fatigue or hairline cracks. Consequently, it should be given adequate consideration in calculation, design, and manufacturing methods, all the more as it is located in the surface where also the calculated working stresses usually attain their maximum values.

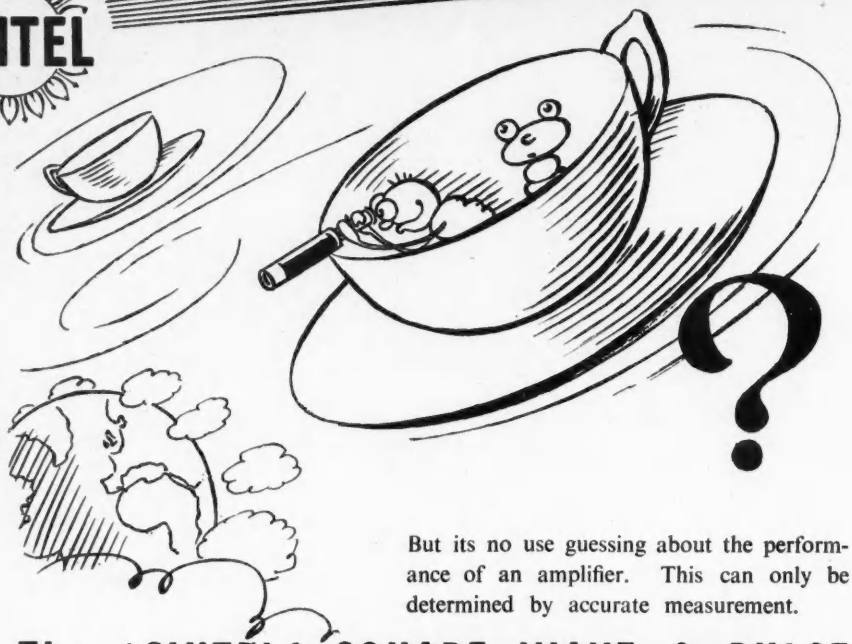
● *ROTATING WELDING ELECTRODE*

Experiments made with a novel welding electrode holder for manual welding, in which the electrode is rotated by means of a small rotor, are reported to have yielded highly promising results. Regardless of any shortcomings the apparatus may have in its present state of development, the following three important inherent advantages of the rotating electrode system have already become evident. Firstly, an inexperienced operator can do better welding with the rotating electrode than he can with conventional equipment. He learns arc manipulation with less training through the use of the rotating electrode. Secondly, lighter-gauge sheet metal can be welded with the rotating electrode than is possible with the conventional equipment where the same diameter electrode is employed in both cases. Thirdly, the rotating electrode welds satisfactorily with less current than conventional equipment for the same electrode size and the same type of weld. Other fields of investigation for this novel equipment may include such items as submerged arc welding and welding of non-ferrous metals and stainless steels. It is also intended to investigate the possibility of developing a mechanism which will give controlled movement to the electrode, as required, by way of example, for a fillet weld. The possibility of mounting multiple electrodes in a variety of arrangements will also be investigated.

● *REMOTE PRESSURE INDICATION*

Where pressure indications have to be transmitted from remote locations to a distant point of observation, extended high-pressure piping can be dispensed with by the use of a novel electrical instrument. The latter employs a transmitter of the tuned oscillator circuit type, its tuning being

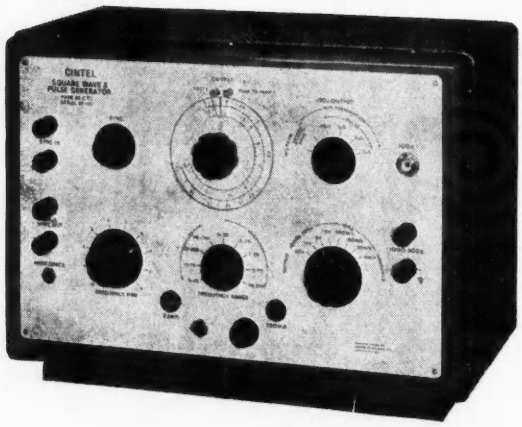
CINTEL



But its no use guessing about the performance of an amplifier. This can only be determined by accurate measurement.

The 'CINTEL' SQUARE-WAVE & PULSE GENERATOR

has been especially designed for testing the transient response of both audio and video frequency amplifiers by the square-wave technique and full technical information is given in our leaflet No. SWG2/1 available on request.



CINEMA-TELEVISION LIMITED

A Company within the J. Arthur Rank Organisation

FOREMOST IN THE MANUFACTURE OF

• Counters & Chronometers • Metal Detectors • Oscilloscopes • Photo-Electric Cells • Cathode Ray Tubes • Geiger-Muller Tubes • Electronic Instruments

WORSLEY BRIDGE ROAD · LONDON · S·E·26

Telephone: HITher Green 4600

Northern Agents:
F. C. ROBINSON & PARTNERS LTD.
287 Deansgate, Manchester 3

Scottish Agents:
ATKINS, ROBERTSON & WHITEFORD LTD.
100 Torrisdale Street, Glasgow, S.2

CINTEL

REGISTERED TRADE MARK

affected by a pressure-sensitive element. This element produces a mechanical balance between the pressure to be registered and the output signal. A pressure variation modifies the deflection of a Bourdon tube, and a mechanical linkage converts the travel of the tube tip into rotary motion of a shaft which is connected through a hair spring to a beam. The movement of the latter serves to detune the oscillator circuit by displacing the oscillator control coil at one end of the beam, which causes a change in plate current. A portion of this current is fed back to a coil at the other end of the beam and in the field of a permanent magnet, thus stabilizing the beam at the signal output level. Ambient temperature variations are eliminated. Thus, temperature effects on the Bourdon tube are opposed and nearly equalled by the change in the modulus of elasticity of the torsion spring, while final compensation is achieved by temperature-responsive resistors in the feedback network. It is claimed that by employing the semi-null balance principle of operation, variations caused by deterioration of the electronic valves, variations in line voltage, or changes in line resistance, are compensated.

● *MAGNETIC PUMPS*

Several types of pumps without stuffing boxes were enumerated in The Blue Pages of our October 1950 issue (page 335). To the list of designs mentioned, an electromagnetic pump of the centrifugal type can now be added. In this design, the pump impeller is driven by an external rotating magnetic field passing across an axial air gap from the stator, which is mounted in a cup-shaped frame. The stator is encased in a housing, which is filled completely with an electrically resistant and heat-conducting material and, on the air-gap side, is faced with a non-magnetic and corrosion-resistant material. The rotor-impeller revolves on a permanently sealed and lubricated heavy-duty ball bearing, which is carried on a stationary shaft. The pump has no seals, no stuffing boxes, no rotating shafts, no couplings, and no separate mounting bases. It can be installed in a pipe like a valve and is completely sealed from the atmosphere. The size to which this pump type can be built is, of course, limited by design considerations affecting the air-gap motor.

● *PICKLING COSTS REDUCED BY NEW PROCESS*

While some alloy steels are frequently pickled with muriatic acid, nitric acid, or mixtures of acids, the common grades of steel are usually pickled with a 6 to 10 per cent sulphuric acid solution. Actually, however, pickling with phosphoric acid is preferable to sulphuric acid pickling. The number of dipping and rinsing tanks is less than in a sulphuric acid pickling system, where rinsing must be more complete. This means lower investment and less floor space occupied. In addition, steel treated with dilute phosphoric acid or a phosphate solution acquires an adherent phosphate coating which is rust-resistant and forms an excellent base for paint. A phosphoric acid pickling treatment generally utilises a solution of 15 to 50 per cent phosphoric acid in water. Frequently, the process also includes chromates, solvents or detergents to assist in removing mill scale, grease and oil. In phosphoric acid pickling, the base metal is less strongly attacked than with sulphuric acid. Besides reducing rinsing requirements, this means that control of the pickling is much simpler, because overtreatment does not result in as high a loss of metal as with sulphuric acid. Hitherto, phosphoric acid pickling has not been used extensively because of the much higher cost of this chemical. A more economical phosphoric acid pickling process has now been announced, however, which depends upon continuous purification and reclamation of the phosphoric acid pickling solution, thus, it is claimed, making the process competitive with sulphuric acid pickling.

● *COMBUSTION-PULSE HEATER*

For the warming-up of car engines and heating of the interior of motor vehicles of all kinds, an ingenious device has just come on the market. It is a very small apparatus 18 inches in length and less than 7 inches in diameter; yet it produces a heating effect of 20,000 B.Th.U. per hour using 0·15 gallons of ordinary motor spirit as fuel.

As described by its makers, fuel and combustion air are conveyed from an encased carburettor through a non-return valve into the combustion chamber. Combustion takes place in the form of a succession of rapid explosions—about 80 per second. From the combustion chamber the gases are passed into a heating coil and silencer. For starting the device, air is provided from a small manually operated pump and motor spirit is also manually injected. Ignition is started by a glow plug operated from the battery of the vehicle, the battery then being cut out. Once the first explosion has taken place the operating cycle perpetuates itself, the explosion pressure being followed by a pressure depression in the combustion chamber. This pressure depression causes the aspiration of the air and fuel mixture through the non-return valve, thus preparing the next cycle. It is interesting to note that this operating cycle is identical with that employed by Karavodine in his experimental explosion-type gas turbine which was built as early as 1908. In this case, the gases were made to produce mechanical work by being discharged through a nozzle upon the blades of a Laval-type turbine runner. It goes without saying that the efficiency of this primitive gas turbine was extremely low, the fuel consumption being some 11 lb of petrol per horse-power hour.

"airflo"

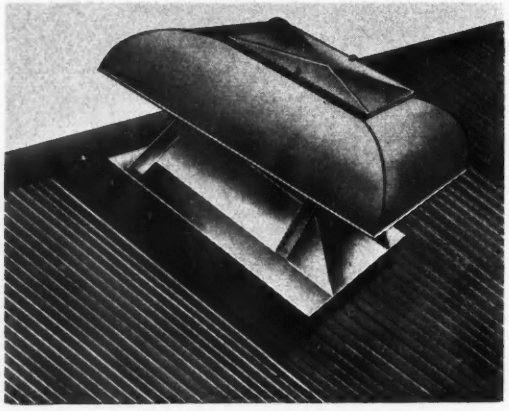
FAN POWERED VENTILATOR

EASILY FITTED TO ANY ROOF

18″ FAN — STANDARD SUPPLY 400 V. 3 ph. 50~. — 3900 cfm

£26 EX WORKS

Subject to current raw material prices.



ALUMINIUM BODY—COMPLETELY WEATHERPROOF

Full Particulars on Request

DUST FUME AIR CONDITIONING VENTILATING PLANTS.

INDUSTRIAL FAN & HEATER COMPANY LIMITED.

ANNE ROAD · HANDSWORTH
BIRMINGHAM 21.

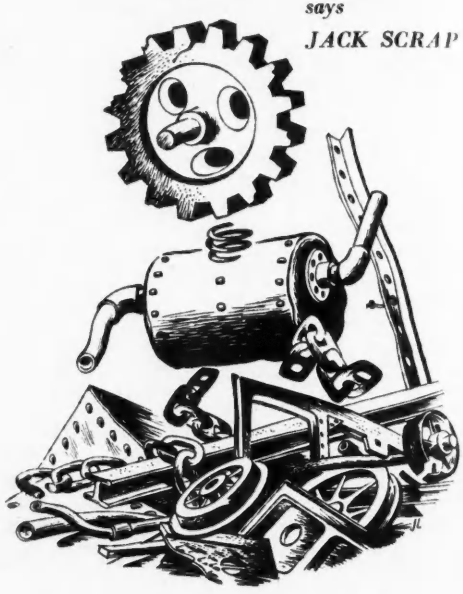
Telegrams: AIRFLO. **Telephone: SMETHWICK 1545/6.**

Northern Area
22 CITY BUILDINGS, 69 CORPORATION ST., MANCHESTER 4

Telephone: BLACKFRIARS 6918

'Get me out of this dump'

says
JACK SCRAP



How many tons of iron and steel scrap would you find in odd corners if you had a thorough search made?

Find that scrap, round it up, turn it in. Every ton of scrap that gets back to the steelworks will make a ton of new steel.

✻ Scrap Merchants are glad to help with dismantling and collection.

Speed the SCRAP Speed the Steel

WANTED
from the
ENGINEERING INDUSTRY
Plate and rod cuttings, wheels and *every kind* of general and process scrap and obsolete plant.

Issued for the STEEL SCRAP DRIVE by the British Iron and Steel Federation

STEEL HOUSE, TOTHILL STREET, LONDON, S.W.1 T.3

● *NOVEL IGNITION SYSTEM FOR AUTOMOBILE ENGINES*

The perfection of a new ignition system of the high-frequency type for automobile engines has just been announced. It utilizes the usual six-volt storage battery and commercial spark plugs, but has no timing breaker points or cam. The system comprises a power supply, a discharge capacitor and a distributor-transformer unit. High-voltage direct current is produced by a vibrator power supply. The distributor-transformer unit houses a high-frequency transformer which rotates with the engine distributor shaft. Both high and low voltage windings of this transformer terminate on distributor fingers, and grounded electrodes co-operate with the primary low-voltage finger. The electrodes are equal in number to the engine cylinders and spaced in correct firing sequence. The secondary high-voltage distributor finger is positioned for alignment with a high-voltage electrode synchronously with the primary finger. While the transformer distributors travel between two electrodes, the power supply charges the discharge capacitor to about 3500 volts. When the primary finger approaches an electrode, the capacitor then discharges through the primary coil of the transformer by sparking across the primary distributor air gap. The resulting high rate of current change through the primary produces the magnetic flux required to induce a high voltage in the secondary coil. The secondary distributor finger passes this high-voltage impulse on to the proper spark plug. An important feature of the system is that each spark receives practically the same energy regardless of the engine speed.

● *ENAMELLING OF ALUMINIUM*

The production of a satisfactory enamel coating on aluminium meets with the difficulty that the stoving temperature of the glazing composition must be below the comparatively low melting point of aluminium, which approximates to 650° C. Also, the coefficient of thermal expansion of the enamel must be about equal to that of the aluminium. Furthermore, the enamel coating must be elastic and flexible so that it does not flake off if the coated surface is bent or dented. A recent process, claimed to meet these requirements, envisages the use of enamelling compositions with a fusion point between 350 and 550° C. By including traces of metal oxides, coloured enamel coatings can be produced by this method. Particular interest attaches to the proposal to apply the vitreous composition by a special spraying method, said to be capable of producing coatings as thin as one thousandth of an inch. For this purpose, a special oil-fired torch has been developed, which differs fundamentally from the usual type of spray pistol in that it throws a cloud of small vitreous particles in a softened state upon the surface to be coated. In order further to assist adhesion and chemical bonding of the coating, the aluminium surface is preheated to 350-550° C.

● *BRAZING FURNACE WITH MOLYBDENUM HEATING ELEMENTS*

The furnace brazing of cemented carbide tool tips in electrically heated muffle furnaces can be considerably speeded up by the employment of resistors of molybdenum wire, which has the advantage of the high melting point of 2700° C as compared with about 1400° C for nickel-chrome material. In a typical muffle furnace of this kind, the molybdenum wires are held in grooves in the refractory ceiling of the muffle, thus subjecting the parts to be brazed to direct radiation. As molybdenum begins to oxidise at temperatures as low as 400° C, a muffle furnace of this type must always be operated with a protective reducing atmosphere, and it is essential to provide this atmosphere prior to starting up the molybdenum heating unit. The reducing atmosphere is conveniently produced by cracking ammonia in a separate cracking chamber, in which ammonia is passed over an incandescent chrome-nickel resistor coil. The cracked product constitutes a mixture of 25 per cent nitrogen with 75 per cent hydrogen, which is then introduced into the muffle. When starting up the furnace, some 20 to 25 minutes will be required to replace the atmospheric air in the muffle by the protective gas. The influence of the furnace temperature upon brazing speed will be gauged from the statement that at 1700° C a given piece could be brazed in 1 minute as compared with 6 minutes at 1250° C. Actually, brazing is carried out at about 1500° C; at this temperature the brazing time is reduced to one-third of that required at 1200° C, and this without causing undue coarsening of the grain structure of the steel component to which the cemented carbide piece is brazed.

● *CATALYTIC EXHAUST FOR PETROL ENGINES*

The invention and commercial development of a catalytic exhaust cleaner is claimed to solve the problem of obnoxious gases exhausted from the petrol engines of lift trucks and similar vehicles operated in warehouses, factories, and generally in enclosed spaces of like nature. The device comprises a specially designed exhaust muffler incorporating a catalyst of unspecified composition, which renders the exhaust gases non-poisonous and odourless. It takes the place of the standard muffler and requires approximately the same space as the latter. The weight of the device is stated to be about twenty-five to thirty pounds, including the necessary supports and brackets. Operation is guarded by a pyrometer installed on the instrument panel. When the temperature is in the indicated " safe range," the

There are

WILD-BARFIELD

ELECTRIC FURNACES

for all heat-treatment

purposes

ELECTRIC WILD BARFIELD FURNACES

* *The illustration shows a General Purpose Furnace for tool-room and production. Temperatures up to* 1050°C.

WILD-BARFIELD ELECTRIC FURNACES LTD.
ELECFURN WORKS, WATFORD BY-PASS, WATFORD, HERTS
Telephone: Watford 6094 (4 lines) Telegrams & Cables: Elecfurn, Watford

M-W.304

blast that dust

A highly concentrated Hymatic hurricane of air at 1,050 m.p.h. will clean sand from castings, swarf from machined parts, and dust from any kind of surface—as cleanly and quickly as a magic wand. Leak-proof and with a scientifically designed convergent-divergent nozzle, this Hymatic blow gun is light to handle and very accurately controllable. Maintenance is negligible. Its extra power makes sure of a clean job in less time and with less air.

Hymatic
BLOW GUN

Please send for leaflet HEC 312/56

The Hymatic Engineering Co. Ltd., Redditch, Worcs.

90

catalytic exhaust is operating satisfactorily. The pyrometer also measures the air-fuel ratio of the engine, enabling constant check on engine efficiency. High temperatures indicate rich mixtures, i.e., excessive fuel consumption, or that the engine is burning excessive oil. The catalytic exhaust is stated to impose no more back pressure on the engine than the standard muffler. For maximum efficiency it is recommended that the catalyst be replaced every three thousand hours of operation. Replacement cost for the catalyst is claimed to be low. It should be noted that the catalytic exhaust is suitable only for unleaded petrol.

● *OVERHEATING OF MINIATURE RESISTORS BY SOLDERING*

Overheating of miniature electronic components during soldering can be prevented by employing a thermal shunt of unique design. This shunt, which is simply a crocodile-type clip to which heavy copper jaws have been added, was developed after research had revealed that the brief overheating caused by soldering operations during the assembly of miniature electronic equipment is liable to produce permanent changes in the value of carbon composition resistors. The seriousness of the problem may be gauged from the fact that such changes may amount to as much as 20 per cent. By attaching the thermal shunt to the component lead wire during soldering and leaving it in place for about 15 seconds subsequent to soldering, the change in value was found to amount to no more than 1 per cent. This improvement is, of course, due to the fact that the shunt dissipates heat which normally reaches the resistor by conduction along the terminal leads. Any heat-dissipating device will assist in this purpose, and, especially in tight places, the use of a pair of long-nosed steel pliers will give reasonably satisfactory results. However, the aforementioned copper-jawed clip was found to be most efficient, particularly as its premature removal is not so likely as with a pair of pliers. The use of such a shunt is recommended for the protection of all types of miniature components, such as small capacitors, chokes moulded in polythene, wire-ended germanium crystals, etc.

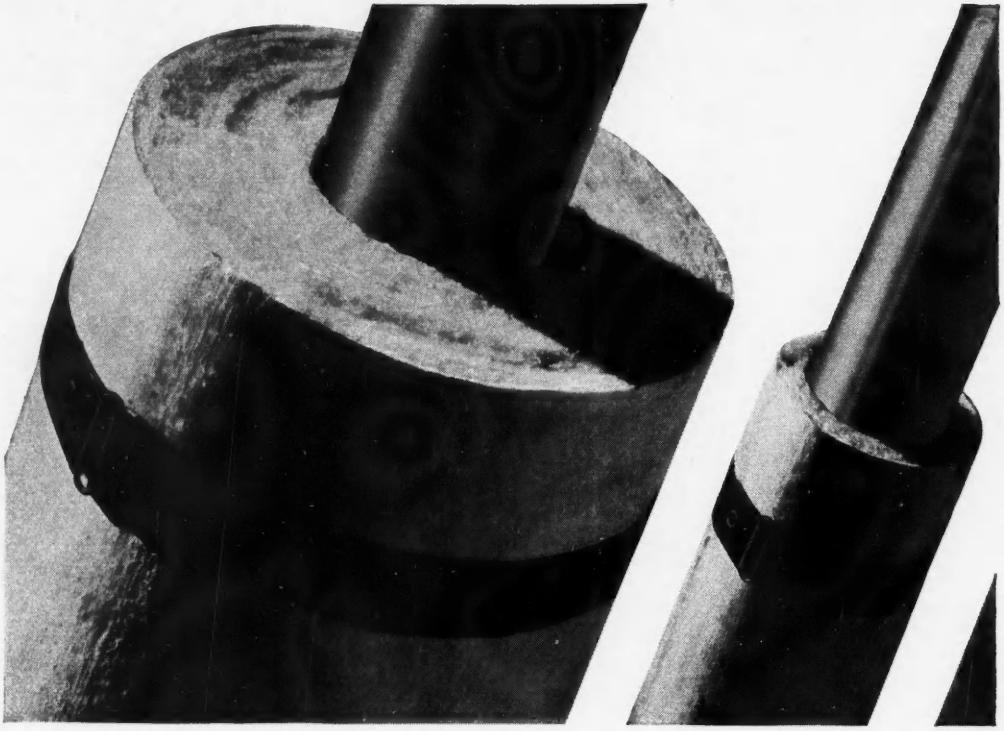
● *HEAT EXCHANGER CLEARING STATION*

In process plants in which heat transfer processes form part and parcel of the plant cycle, the maintenance of heat exchanger surfaces in clean condition is of vital importance. The installation at a major refining plant of a cleaning station to which the heat exchanger bundles are taken for periodical cleaning must, therefore, be considered to mark a significant development. In this installation, a high-velocity jet of pressure water throws abrasive blasting sand upon the surfaces to be cleaned. This method is expected to maintain the average heat transfer coefficients some five per cent higher than can be obtained with dry sand blasting, drilling, or acid pickling; and this will result in a corresponding rise in overall plant capacity. The tube bundle cleaning installation consists chiefly of the sealed cleaning room proper, a source of fresh sand and water, one or more high-pressure guns or nozzles, and a circulating and separating system to remove sludge and water and to recover usable sand. The water is supplied at 1200 psi pressure to the gun which aspirates clean blasting sand at the rate of some 100 lb per hour. The guns are manually operated, the operator outside the cleaning room directing the gun by pointing it between close-fitting rubber lips of a slot which extends over almost the entire length of one wall at a height of about 3½ feet above the floor. The wall is, of course, fitted with suitable windows for observation of the cleaning process.

● *MACHINING AND HARDENING IN THE SAME MACHINE TOOL*

A most interesting and promising attempt has been made to carry out the heat treatment of a component part before its removal from the machine tool in which it is produced. The particular case referred to concerns the production of automotive universal joint bearing races and flanged bearing races on an eight spindle automatic. Six of its positions are employed in completely machining the part, while at the seventh an induction hardening attachment is installed. After heat treatment, cut-off is carried out at the eighth position. The induction hardening equipment is mounted on a gallery directly over the machine tool, each unit serving two automatics. In addition to lowering manufacturing cost, this innovation simplifies production insofar as it eliminates a number of secondary operations, including those required for the carburizing process. The original report lays particular stress upon the fact that the specified hardening pattern is perfectly controllable and reproducible. This was achieved by the development of a special hardening attachment, which includes a small oil-cooled coil fitting within the bore of the work. The surface to be hardened is oil-quenched, the quenching being initiated the instant the part has begun to heat up. It goes without saying that manufacturing procedures of this kind should be capable of application to a considerable number of operations which involve machining and subsequent heat treatment of small component parts.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.



Insulation **THICK** and THIN in Fibreglass Rigid Sections

- High thermal efficiency
- Mechanically strong
- Minimum thickness required
- Wall thicknesses from ½″ to 2″
- For pipes of ½″ to 12″ bore
- Easily applied
- Readily available
- Neat in finished appearance

TRADE **FIBREGLASS** MARK

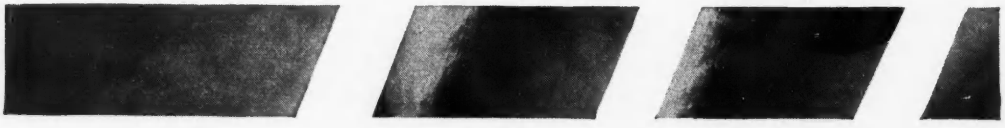
For structural heat and cold insulation. Sound deadening. Acoustic correction. Porous membranes for pipe wrapping, flooring, roofing. Battery separators and air filters. In textile form for electrical insulation and flameproof decorative fabrics.

FIBREGLASS LTD., RAVENHEAD, ST. HELENS, LANCS. (ST. HELENS 4224)

LONDON OFFICE:
63/65 Piccadilly, W.1 (Regent 2115/6)

GLASGOW OFFICE:
136 Renfield St. (Douglas 2687)

NEWCASTLE-ON-TYNE OFFICE:
c/o Pilkington Brothers Ltd., Westgate Rd.
(Newcastle 20938)



THE ENGINEERS' DIGEST
REVIEW OF WORLD ENGINEERING PROGRESS
VOL. XII. No. 3 MARCH, 1951

Raw Materials—A Solution

MATERIAL shortages and price increases are giving serious concern to industrialists everywhere. Whilst the world is craving for moral and economic stability, these two evils work incessantly to lower our standards and tend to perpetuate uncertainty.

The International Materials Conference in Washington, a bureaucratic machinery set up by twelve nations, is busily engaged in lengthy conferences to determine whether or not there should be international allocation and price control of critical materials. Whilst these discussions are going on, it has been revealed that world production of tin at the present rate of 161,000 tons per annum is 16,000 tons in excess of current annual consumption. At the same time, the shortage of tin has caused stoppages in vital production as well as a great deal of panic-buying at fabulous prices, and has contributed to creating an atmosphere in which prices are forced up to an unjustifiably high and indeed dangerous level.

The sudden rearmament effort of the Western Powers has come at a time when rebuilding from the ruins of World War II has not yet been completed, and labour and material resources have been employed to capacity. The inflationary tendency can, therefore, be readily understood.

The jump in prices of raw materials is interfering, however, with the internal conditions of the free countries. The rise in the cost of living threatens industrial unrest and inflation. It threatens to upset the financial stability of the Western World and the economic basis of rearmament itself.

The forces of inflation must, therefore, be restrained at all costs. Fiscal measures and physical controls can achieve some slowing-down of the inflationary process. Greater productivity is, however, the only means by which inflation can be checked and stability and confidence restored.

Engineers and metallurgists can play an outstanding rôle in solving these all-important problems. New engineering materials can be created. Substitute materials can often replace critical materials, and new methods can be found to save and to replace what is scarce.

A few very recent developments will indicate the overwhelming importance of employing technical brains in the interests of greater productivity and sounder industrial economy.

Electrolytic tinplating saved a substantial amount of tin by enabling tinplate manufacturers to apply thinner coatings than had been possible by the dipping process. Important additional savings have already resulted from a new method perfected in the United States by the Weirton Steel Company, by which the thickness of the coatings on either side of the plate can be varied at will. For instance, orthodox coating of $1\frac{1}{2}$ pounds per base box calls for the distribution of $1\frac{1}{4}$ pounds basis of tin on both sides of the plate. The Weirton technique can use one pound on the inside to protect the contents of the containers, and $\frac{1}{4}$ pound on the outside to protect the containers from exposure. The saving in pig tin is 50 per cent. Tin-free containers in which a plastic cement is used instead of solder for side-seams are now undergoing extensive tests by several oil and anti-freeze manufacturers.

In the interests of alloy conservation, Walter E. Jominy, of the Chrysler Corporation, Detroit, the internationally known metallurgist, advocates the use of boron-treated carbon steels for quenched and drawn automotive parts. New boron-treated steels are now manufactured in the United States by five large steel companies for use in the automotive and agricultural industries. These new steels are about 5 per cent cheaper than standard grades, and were designed to save 50 per cent in the use of scarce nickel, chromium and molybdenum.

The scarcity of sulphur and sulphuric acid speeded up the construction of a plant at the Noranda Mines in Canada for the extraction of sulphur from iron pyrites. This new process is of very great importance, as deposits of iron pyrites are available which contain, it is estimated, 750 million tons of sulphur. This would meet the needs of the steel, rayon, paper and other manufacturing industries for decades.

The redesign of loudspeakers by the Radio Corporation of America resulted in a nine-tenths reduction of the amount of cobalt needed in the average television receiver. The use of aluminium has been halved by redesign of antennae, and other technical developments announced by the R.C.A. also make for great savings in copper, nickel, brass, and steel.

During the last war, this journal concentrated on drawing the attention of the engineering industries to substitute materials, and to new design features which enable savings in scarce materials. We shall continue to do so in the critical times ahead, for it is felt that such information supplemented by systematic and concentrated effort to initiate processes aimed at increasing productivity will be of the greatest consequence.

Improving Internal Combustion Engine Efficiency by means of Exhaust Gas Utilisation

By G. MANGOLD. (From *Motor-Technische Zeitschrift* (*MTZ*), Vol. 11, No. 5, September-October, 1950, pp. 114-117, 13 illustrations.)

Great interest has been shown by our readers in a short note "Improving internal combustion efficiency" published in The Blue Pages of our December 1950 *issue. We have therefore decided to include in this issue an extensive abstract of the original article.*

THE efficiency of an internal combustion engine reaches its maximum value if the combustion gases are expanded to the ambient temperature. In actual fact, however, the combustion gases are exhausted at considerably higher temperatures.

The following calculations are based on an ideal process without losses, in which the combustion gases are expanded to ambient temperature. It is assumed that air is the working medium and that it behaves as an ideal gas. Fig. 1 shows the cycle with heat supplied at constant volume, and Fig. 2 shows the cycle for heat supplied at constant pressure.

The cycle efficiencies are given by

$$\eta_{th} = 1 - (Q_2/Q_1), \text{ or}$$

$$\eta_{th\ v,\ p} = 1 - (c_{v,\ p}\ T_0/Q_1) \log_e B_{v,\ p}$$

where $B_{v,\ p} = 1 + Q_1/(c_{v,\ p}\ T_0\ r^{\gamma-1})$.

In these equations, the subscripts v and p refer to the cycles with heat supplied at constant volume and at constant pressure, respectively, Q_1 = heat supplied [kcal/kg], T_0 = ambient temperature [°K = °C$_{abs}$], c_v and c_p = specific heats [kcal/(kg °C)], $\gamma = c_p/c_v$, $r = V_0/V_1$ = compression ratio. When $Q_1 = 0$, $\eta_{th} = 1 - (T_0/T_1)$.

Figs. 3 and 4 show the theoretical efficiency plotted against the compression ratio r for $Q_1 = 500$ kcal/kg and $T_0 = 293$ °K. For comparison, the efficiencies of the Carnot, Diesel and Otto cycles are also given.

Comparison of the curves "a" for the theoretical cycles with the curves "c" for the Otto and Diesel cycles shows that the efficiency of the internal combustion engine can be considerably improved. In practice, the difficulty is that large volumes and high pressures are required for this purpose. The following sections, however, describe a method by means of which values can be achieved which are considerably closer to the theoretical efficiencies.

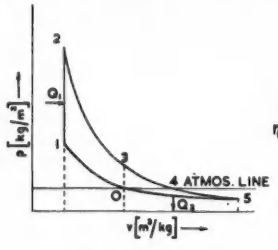


Fig. 1.

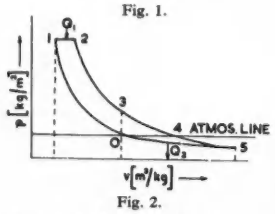


Fig. 2.

0–1 = adiabatic compression ;
1–2 = heat supply Q_1 [kcal/kg] ;
5–0 = heat removed Q_2 [kcal/kg] ;
2–5 = adiabatic expansion ;
5–0 = isothermal compression ;
p_0 = ambient pressure [kg/cm²] ;
T_0 = ambient temperature in °K ;
0–1–2–3 = Otto or Diesel cycle.

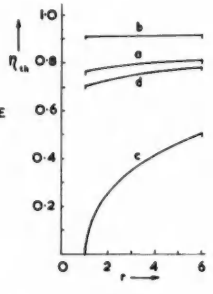


Fig. 3.

a = efficiency η_{th} for heat supply at constant volume and expansion to $T_0 = 293$ °K, for $Q_1 = 500$ kcal/kg ;

b = efficiency η_{th} for the Carnot cycle ;

c = efficiency η_{th} of the Otto cycle, for $Q_1 = 500$ kcal/kg and $T_0 = 293$ °K ;

d = efficiency η_{th} of the Otto cycle with exhaust gas utilisation using compressed air.

THEORETICAL CYCLE

The cycle requires the use of an internal combustion engine, a heat exchanger, a compressor and an after-cooler. Assuming perfect heat exchange between the exhaust gases and the compressed air, 1 kg of compressed and heated air will contain the same quantity of heat as 1 kg of exhaust gases at the same temperature. The air is compressed isothermally and the pressure ratio is so high that the air will expand with the same pressure ratio down to ambient temperature. This compressed air cycle is illustrated in Fig. 5. The air is compressed from its initial condition (1 atm, 293 °K) isothermally along 8-9. Heat transmission from the exhaust gases occurs along 9–10, and 10–8 represents the adiabatic expansion of the air to its initial condition. Denoting by "6" the condition of the exhaust gases after leaving the engine, we have

$$i_3 - (p_3\ v_0/\mathit{J}) = i_6 - (p_0\ v_0/\mathit{J})$$

where i = enthalpy (i.e., total heat), and J = mechanical equivalent of heat. Therefore,

$$i_6 = i_3 - c_v(\gamma - 1)\ (T_3 - T_0)$$

or

$$T_6 = (T_3/\gamma) + (T_0/\beta),$$

where $\beta = \gamma/(\gamma - 1)$.

In this compressed-air cycle 8–9–10, we have $T_8 = T_0$ and $T_{10} = T_6$ (complete heat exchange), so that the heat value of the work available is

$$E/\mathit{J} = i_6 - i_0 - c_p\ T_0 \log_e (T_6/T_0) \quad \text{[kcal/kg]}$$

For the Otto cycle, we have

$$T_3 = T_0 + Q_1/(c_v\ r^{\gamma-1}) = T_0\ B_v$$

so that

$$i_6 = T_0\ c_p + (Q_1/r^{\gamma-1}) \text{ and } T_6 = T_0\ B_p$$

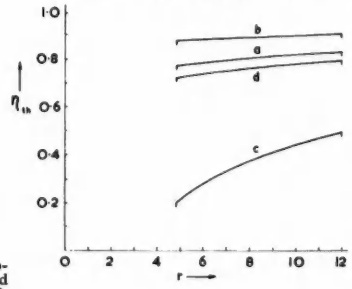


Fig. 4.

a = efficiency η_{th} for heat supply at constant pressure and expansion to $T_0 = 293$ °K, for $Q_1 = 500$ kcal/kg ;

b = efficiency η_{th} of the Carnot cycle ;

c = efficiency of the Diesel cycle, for $Q_1 = 500$ kcal/kg and $T_0 = 293$ °K ;

d = efficiency η_{th} of the Diesel cycle with exhaust gas utilisation using compressed air.

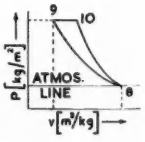


Fig. 5.

8–9 = isothermal compression ;

9–10 = heat supply at constant pressure from the exhaust gases ;

10–8 = adiabatic expansion.

with $B_{v,p} = 1 + \left\{Q_1/(c_{v,p}\, T_0\, r^{\gamma-1})\right\}$,

as previously defined.

The overall efficiency of the Otto cycle with exhaust gas heat utilisation is given by

$$\eta_{th} = 1 - r^{-(\gamma-1)} + r^{-(\gamma-1)} - (c_p\, T_0/Q_1) \log_e (T_6/T_0)$$

or $$\eta_{th} = 1 - (c_p\, T_0/Q_1) \log_e B_p.$$

Curve " d " of Fig. 3 shows η_{th} as a function of r for $Q_1 = 500$ kcal/kg and $T_0 = 293$ °K.

For the Diesel cycle, we have

$$T_3 = T_0\, B_p^{\gamma}$$

so that $$i_6 = c_v\, T_0\, B_p^{\gamma} + c_v\, T_0\, (\gamma - 1)$$

and $$T_6 = (T_0/\gamma)\, B_p^{\gamma} + (T_0/\beta)$$

where $\beta = \gamma/(\gamma - 1)$. The overall efficiency of the Diesel cycle with exhaust gas heat utilisation is, therefore,

$$\eta_{th} = 1 - (c_p\, T_0/Q_1) \log_e [(B^{\gamma}/\gamma) + (1/\beta)].$$

Curve " d " in Fig. 4 shows η_{th} plotted against r for $Q_1 = 500$ kcal/kg and $T_0 = 293$ °K.

Using the same basic values for Q_1 and T_0, we obtain the following results:—

	Exhaust gas temp. T_6	Available work of compressed air process $E/\mathcal{J}$	Pressure ratio p_{10}/p_8
Otto cycle	1309 °K	138·5 kcal/kg	—
Diesel cycle	1385 °K	153·7 kcal/kg	$(T_{10}/T_8)^{\beta}$

Fig. 6 shows the available work $E/\mathcal{J}$ and the pressure ratios p_{10}/p_8 required for various temperatures T_{10} of the compressed air, in °K.

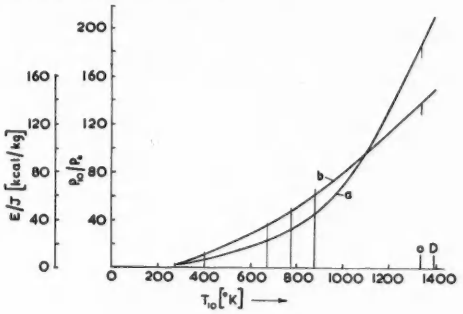


Fig. 6.
a = pressure ratio p_{10}/p_8; available work $E/\mathcal{J}$.

For incomplete heat exchange, we have $T_{10} = T_6 - \Delta t$, where Δt = temperature difference between the temperatures of the compressed air and the exhaust gases leaving the heat exchanger.

In practice, isothermal compression can only be achieved by adiabatic compression in several stages with inter-cooling. For this reason, the available work of the compressed-air process will now be calculated for single- and multi-stage compression.

The compressed-air process with multi-stage compression and complete expansion to the initial pressure p_0 is shown in Fig. 7, while Fig. 8 shows the process for incomplete expansion.

In the case of the process of Fig. 7 with an n-stage compression, the work available is

$$E/\mathcal{J} = c_p\, T_{10}\, [1 - r'^{-(\gamma-1)/n}] - nc_p\, T_0\, [r'^{(\gamma-1)/n} - 1]$$

where n = number of stages, r' = compression ratio of a single stage, so that $p_9'/p_0 = r'$ and $p_9/p_0 = r'^{n\gamma}$.

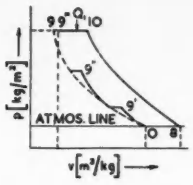


Fig. 7.

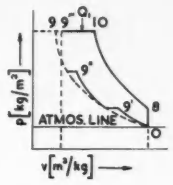


Fig. 8.
0–9 = isothermal compression; 10–8 = adiabatic expansion.

The available work $E/\mathcal{J}$, regarded as a function of the compression ratio r', reaches a maximum value $(E/\mathcal{J})_{max}$ when

$$r' = (T_{10}/T_0)^{1/\delta}$$

where $\delta = (\gamma - 1)(n + 1)$. Therefore,

$$(E/\mathcal{J})_{max} = c_p\, T_{10}\, [1 - (T_{10}/T_0)^{-n/(n+1)} - nc_p\, T_0\, [(T_{10}/T_0)^{1/(n+1)} - 1]$$

and $$p_9/p_0 = (T_{10}/T_0)^{n\gamma/\delta}.$$

For $n \to \infty$ we have

$$(E/\mathcal{J})_{max} = c_p\, (T_{10} - T_0) - c_p\, T_0 \log_e (T_{10}/T_0)$$

and $T_8 = T_0$, that is, the process takes place with isothermal compression, as shown in Fig. 5.

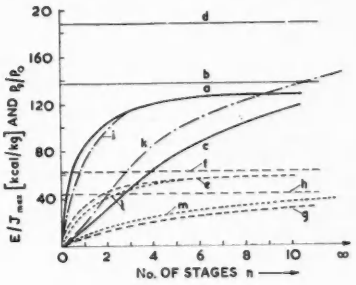


Fig. 9.

a and e = $(E/\mathcal{J})_{max}$ [kcal/kg] b and f = asymptotic value of $(E/\mathcal{J})_{max}$ for $n \to \infty$ c and g = p_9/p_0 d and h = limiting value of p_9/p_0 for $n \to \infty$	For expansion to p_0, $T_{10} = 1309$ °K and 873 °K respectively, and $T_0 = 293$ °K
i and l = $(E/\mathcal{J})_{max}$ [kcal/kg] C and f = asymptotic value of $(E/\mathcal{J})_{max}$ for $n \to \infty$ k and m = p_9/p_0 d and h = limiting value of p_9/p_0 for $n \to \infty$	For incomplete expansion $T_{10} = 1309$ °K and 873 °K respectively, and $T_0 = 293$ °K

Fig. 9 shows the maximum work $(E/\mathcal{J})_{max}$ and the overall pressure ratio p_9/p_0 as functions of the number of compression stages n.

The process of Fig. 8 with incomplete expansion and n compression stages gives the available work

$$E/\mathcal{J} = c_p\, T_0 \left[(n-1) + (1/\gamma) - nr'^{\gamma-1} + (T_{10}/T_0) - \left\{(T_{10}/T_0)^{\gamma}/\epsilon\right\}\right]$$

where r' = compression ratio of one stage, and

$$\epsilon = \gamma r'^{n\gamma(\gamma-1)}.$$

Therefore, $p_9'/p_0 = r'$ and $p_9/p_0 = r'^{n\gamma}$. The work reaches a maximum value when

$$r' = (T_{10}/T_0)^{1/\delta^*}$$

where $$\delta^* = [(\gamma - 1)(n\gamma + 1)]/\gamma.$$

Then

$$(E/\mathcal{J})_{max} = c_p T_0 \left[(n-1) + (1/\gamma) + (T_{10}/T_0) - (T_{10}/T_0)^{\gamma/(n\gamma+1)} \times \left\{n + (1/\gamma)\right\}\right]$$

and $$p_9/p_0 = (T_{10}/T_0)^{n\gamma/\delta^*}.$$

When $n \to \infty$, we have

$$(E/\mathcal{J})_{max} = c_p (T_{10} - T_0) - c_p T_0 \log_e (T_{10}/T_0),$$

that is, the process takes place with isothermal compression as shown in Fig. 5. The values for $(E/\mathcal{J})_{max}$ and p_9/p_0 are plotted in Fig. 9.

It is apparent from Figs. 8 and 9 that with small values of n, the maximum work increases rapidly at first, and for larger n values it approaches the asymptotic value for $n \to \infty$ at a much slower rate.

The variation of the available work $E/\mathcal{J}$ as a function of the pressure ratio p_9/p_0 for complete expansion to the initial pressure p_0 is shown in Fig. 10 for the case of single-stage compression.

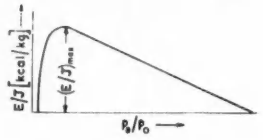


Fig. 10.

In order to obtain this process under practical conditions, it is necessary to have a heat exchanger and a single- or multi-stage positive-displacement or flow-type air compressor. The air can be used in an open cycle. However, if the air is put through a closed cycle, and the pressure of the expanded circulating air is chosen higher than that of the ambient air, considerably smaller dimensions can be obtained for the air compressor and for the air expansion machine than in the case of the open-cycle process. The closed-cycle arrangement requires an after-cooler for the expanded circulating air. The compressor and the expansion machine may be built with the internal combustion engine as a single unit or developed as separate designs.

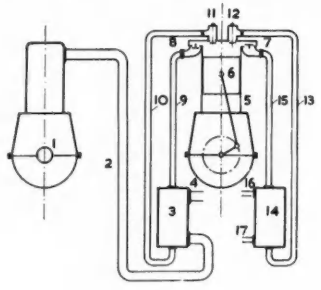


Fig. 11.

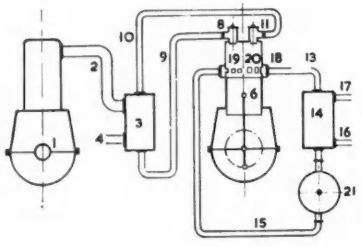


Fig. 12.

CYCLE USING POSITIVE-DISPLACEMENT TYPE COMPRESSORS

When positive-displacement type compressors are used and the compression and expansion of the circulating air occur in the same cylinder, the process is as shown in Figs. 11 and 12. The compression and expansion cylinder operates as a 4-stroke cycle machine in Fig. 11, and as a 2-stroke cycle in Fig. 12.

The installation shown in Fig. 11 operates in the following manner:—During the first downward motion of the piston (6), the inlet valve (7) is opened and allows air to enter cylinder (5) at a pressure of, say, 4 atmospheres, from conduit (15). During the second stroke, corresponding to the upward motion of the piston, this air is compressed to, say, 30 atmospheres. The exhaust valve (8) is then opened and during the remainder of the stroke this compressed air is then discharged into the heat exchanger (3), in which its temperature is raised. At the end of this stroke, the exhaust valve (8) closes. During the third stroke, corresponding to a downward motion of the piston (6), the inlet valve (11) opens, and allows the air to flow into the cylinder at a higher temperature. After the cylinder is filled, the inlet valve (11) closes, so that the air will expand during the further piston travel. Towards the end of the stroke, the exhaust valve (12) opens, and the charge in the cylinder can now expand into the after-cooler (14), in which the pressure is equal to, say, 4 atmospheres. During the fourth, upward, stroke of the piston, the charge is ejected into the after-cooler (14). The entire cycle begins again with the fifth, downward, stroke of the piston. Thus, cylinder (5) operates on a 4-stroke cycle.

In the cycle according to Fig. 12, the compression stroke and the charging and expansion strokes occur as in the 4-stroke cylinder of Fig. 11. During the first stroke, corresponding to the downward motion of the piston (6), when the cylinder is filled with the heated compressed air, the piston opens the exhaust ports (20) towards the end of the stroke. The charge in the cylinder expands through these into the after-cooler (14), which is at a pressure of, say, 4 atmospheres. During the further motion of the piston, the scavenge ports (19) are opened, so that the cylinder is scavenged by compressed air obtained by means of a circulating pump (21) which maintains a small pressure in excess of the pressure in the after-cooler (14).

During the following second stroke, corresponding to the downward motion of the piston, the scavenge and exhaust ports are closed by the piston, and compression begins. The 2-stroke working cycle is then repeated.

PROCESS WITH AN INTERNAL COMBUSTION ENGINE UNDER ACTUAL OPERATING CONDITIONS

The cycle with a single-stage compression of the circulating air, using a gas engine, gives the following results on the basis of a rough calculation:—

Gas engine data: economic efficiency $\eta_e = 0{\cdot}28$; exhaust gas temperature 650 °C; heat supplied for a charge of 1 kg: 450 kcal; air temperature ahead of compressed air cylinder 600 °C; swept volume for 1 kg charge at 1 atmosphere and 20° C, and an air delivery ratio $\lambda = \frac{1}{2}$: $V = 0{\cdot}86$ m³; mean effective pressure $p_e = 6{\cdot}25$ kg/cm².

Data of compressed-air machine: the pV-diagram of the compressed-air cylinder is shown in Fig. 13 for the air delivery ratio $\lambda = 1$ and the residual space $V_{res} = 0$; pressure ratio of circulating air $p_2/p_1 = 9{\cdot}0$; mechanical efficiency $\eta_m = 0{\cdot}85$; diagram efficiency ratio = 0·9.

The available work is $(E/\mathcal{J})_{eff} = 1{\cdot}1 \times 0{\cdot}9 \times 0{\cdot}85 \times 35{\cdot}4 = 29$ kcal for a charge of 1·1 kg. Owing to the higher specific heat of the exhaust gases, 1 kg of exhaust gases can heat 1·1 kg of air.

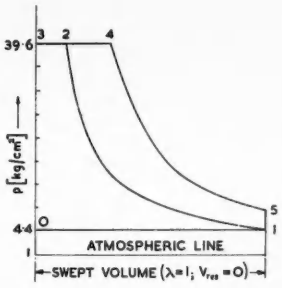


Fig. 13.
0–1 = suction line;
1–2 = adiabatic compression;
2–3 = ejection line;
3–4 = charging line;
4–5 = adiabatic expansion;
5–1–0 expansion and ejection line.

The overall efficiency with exhaust gas heat utilisation is then

$$\eta_{total} = 0{\cdot}28 + (29/450) = 0{\cdot}28 + 0{\cdot}065 = 0{\cdot}35,$$

this giving an improvement in the heat utilisation and an increase in power of 25 per cent.

Assuming that the compressed-air cylinder has a swept volume $V = 0{\cdot}215$ m³, the mean effective pressure in this cylinder will be

$$p_e = 29 \times 427/(0{\cdot}215 \times 10^4) = 5{\cdot}75 \quad kg/cm^2,$$

the induction pressure is

$$p_1 = 1{\cdot}1 \times 29{\cdot}3 \times 293/(0{\cdot}215 \times 10^4) = 4{\cdot}4 \quad kg/cm^2$$

and the maximum pressure is

$$p_2 = 4{\cdot}4 \times 9 = 39{\cdot}6 \quad kg/cm^2.$$

The combustion cylinders of the gas machine have a total swept volume which is four times greater than that of the compressed-air cylinder. The complete installation would consist, for instance, of four engine cylinders and one compressed-air cylinder, which could be combined to form a single power plant.

U. S. A.

Freeze Drying

By W. H. MOHRHOFF. (From *Powerfax*, Vol. 28, No. 4, 1950, pp. 4-7, 4 illustrations.)

A very useful tool in the unit processes available to the pharmaceutical or biological manufacturer is the removal of water vapour by sublimation. By this physical phenomenon, heat-sensitive drugs or biologicals can be dried with a minimum of denaturisation of the proteins, and with no over-heating which would inactivate the therapeutic factors.

THIS process of drying from the frozen state is carried out by subjecting the material to be dried to low absolute pressures after they have been previously frozen at temperatures lower than — 40° F. At absolute pressures lower than about 3 mm of mercury, water ice will sublime, i.e., it will pass from the solid to the gaseous state without becoming a liquid.

In commercial practice, this type of drying is used to dehydrate valuable biologicals, serums, hormones, etc., which are destroyed or impaired at normal drying temperatures, which must be kept at refrigerated temperatures in solution to prevent spoilage, or which are unstable for long periods in aqueous solution.

In carrying out freeze drying, a vacuum-type chamber or system, connected to a source of high vacuum and a means of removal of water vapour, constitutes the essential apparatus. If a mechanical pump or diffusion pump is used as a source of vacuum, a low-temperature condenser or a chamber containing moisture-absorbing material is employed intermediately between the drying chamber and the source of vacuum. If a multi-stage steam jet ejector with barometric condenser is employed, there is no need for mechanical devices for removing condensed water vapour. In general, the multi-stage steam jet with barometric condenser is the simpler arrangement and has a lower initial cost when compared with mechanical pumps, diffusion pumps, and low-temperature condensers. There is also an advantage in the fact that steam jets are somewhat easier to maintain. However, the choice of steam jets is entirely dependent upon the pressure and quantity of steam available, and upon the physical location of the vacuum chamber and multi-stage steam jets. With a barometric condenser, one must obviously have at least a 35-ft elevation between the condenser outlet and the invert level of the hotwell. In practice it is much safer to increase this distance to 45 ft. This is done to overcome possible changes in hotwell level, sudden surges of cooling water, or sudden leaks in the leg between condenser and hotwell.

The most common type of vacuum chamber has a cast-iron shell with a gasketed door. The unit has hollow shelves which can be cooled or heated by recirculation of glycol, Cello-solve, or alcohol solutions. Some vacuum chambers do not have hollow shelves, but employ infra-red heating elements and highly polished reflectors. The basic procedure for freeze drying is roughly as follows :—

The material to be dried is pre-frozen in glass bottles or flat shallow trays. The technique using glass bottles allows the bottle to rotate in a refrigerated bath with its axis in a horizontal plane. As a result of this treatment, the liquid freezes in a cylindrical shell inside the periphery of the bottle. The material, if dried in shallow trays, is frozen by merely immersing the tray in the refrigerated bath, taking care to keep the bottom of the tray parallel with the liquid level so that a uniform thickness of ice is formed. In the case of either technique, it is not advisable to have the thickness of ice much greater than $\frac{7}{8}$ in., since the rate of diffusion of water vapour through ice of a thickness in excess of 1 in. is greatly diminished. The freezing must take place at a temperature of —40° F or lower in order to prevent separation of protein fractions which have lower melting points than water itself. In other words, if freezing is allowed to proceed at too slow a rate because of a warm bath of refrigerant, the protein materials would tend to concentrate near the top of the shallow tray or at the inside of the shell-frozen bottle. In actual drying then, there would be a tendency for these fractions to thaw out upon application of heat. This thawing would give a denatured product which could not be completely reconstituted, or which might impair the therapeutic agent in the material.

After the material has been frozen, it is then stored at a subzero temperature until it can be dried, or it may be placed directly into a chilled dryer from the freezing bath. In the drying process, material is quickly transferred from either the bath or the storage cabinet to the chamber dryer. The chamber should preferably be previously chilled to about 0° F by circulating cold refrigerant through the shelves. The chamber is quickly sealed up after transfer of the material and put under vacuum as soon as possible. When the absolute pressure reaches 3 mm, or lower, the danger of thawing down is minimised and the operator's worries are temporarily over. If a temperature record is made of the material in the dryer from this point on, and if the

apparatus is functioning properly, the material will drop steadily in temperature because the vaporisation of water results in an absorption of heat. Therefore, after equilibrium has been reached, it becomes necessary to introduce heat into the circulating medium from an external source. The most common heaters are of the electrical type, which can be controlled by automatic equipment so as to give off-and-on control. Considerable heat can be applied at the initial stages of the drying despite the fact that the material must be kept frozen, and it is not uncommon to see 25° F differentials between materials being dried and the temperature of the medium circulating in the dryer shelves. When the water content of the product approaches 10 to 15 per cent, usually a sharp and marked change takes place in the appearance of the material in that it tends to shrink or break away from the side walls of the bottle or the tray. When this breaking point occurs, it is more difficult to get heat into the product by conduction because it actually does not touch the container in very many places, and a greater differential of temperature between the material and the heating medium must be maintained. When the moisture contents of 1 per cent or lower are approached, the temperature of the product suddenly approaches the temperature of the heating medium and serves as an indicator that drying is in the final stage. Care must be taken at this point in the drying process to ensure that the heating medium shall not exceed a temperature which will impair the therapeutic agent in the material. Just prior to reaching the terminal temperature, it is advisable to shut off the heating source in order to allow for any lag due to heat capacities in the apparatus.

At the end of the drying period, the vacuum chamber is usually shut off from the source of vacuum and the vacuum released by introduction of inert gas or dry and filtered air.

Freeze drying, lyophilising, or gelsiccating are one and the same technique, and their principles have been known for many years. Up until five or six years ago, the technique was used mostly in small laboratories and clinics. The impetus of the human plasma program of World War II has made this technique a valuable processing tool for the chemist and chemical engineer. Many commercial installations are now complete and operating in the pharmaceutical industry on production of valuable products, such as penicillin, streptomycin, serum albumin, thrombin, etc. In the food industry, this technique has found its way into a number of plants, some of which employ semi-continuous equipment for the preparation of soluble coffee, pectin, dehydrated orange juice, dehydrated soup, etc.

CZECHOSLOVAKIA

An Unusual Case of Critical Speeds in Centrifugal Pumps

By P. KOHN. (From *Strojnický Obzor*, Vol. 30, No. 12, December 1950, pp. 187-188, 2 illustrations.)

The distance bushes between the impellers, the impeller hubs, and the shaft sleeves in the stuffing boxes of centrifugal pumps reinforce the shaft. The degree of stiffening depends on the clearance between the bushes and the shaft, and on the deflection of the shaft.

A HIGH-PRESSURE seven-stage pump showed vibrations of the shaft at 2500 to 3000 rpm. The bushes and impellers had a sliding fit on the shaft. The diameter of the shaft where it carries the impellers was originally 75 mm, and this shaft was replaced by one of 80 mm diameter, which, however, did not noticeably improve matters. It is interesting to note that six-stage, but otherwise identical, pumps had been running for many years without trouble.

The assembled rotor (shaft diameter 80 mm) was tested by observing its running in air. Critical speeds were found to be in the neighbourhood of 1800 rpm, and these were already more pronounced in the neighbourhood of 2400 rpm. The different behaviour inside and outside the pump can be explained by the different damping action of air and water, and by the fact that the lower critical speed had probably previously been overlooked.

The critical speeds were calculated for two different assumptions :

I. If the reinforcing influence of the bushes and impellers is neglected, the first critical speed for a seven-stage pump, with a shaft 75 mm in diameter, is $n_1 \triangleq 1600$ rpm; for a diameter of 80 mm, it is $n_1 \triangleq 1800$ rpm; and for a six-stage pump, shaft diameter 75 mm, it is $n_1 \triangleq 1900$ rpm.

II. If the reinforcing of the bushes and impellers is considered, on the assumption of no clearance between the latter and the shaft, the critical speeds in the three cases are $n_2 \triangleq 2500$ to 2800 rpm, $n_2 \triangleq 2500$ to 2800 rpm, and $n_2 \triangleq 3200$ to 3500 rpm. Because of the uncertainty of the reinforcing influence of the impeller hubs, onlv ranges of the critical speed could be stated. The identity of the critical speeds in the first two cases is due to the fact that the outer contour of the shaft did not change with the diameter of the shaft.

The calculated critical speeds agree closely with those observed, and also show that, for the six-stage pump, they are well above the running speed, but they do not explain why the two critical speeds are not of the ratio 1 : 2, as could have been expected.

The critical speed grows with the stiffness of the shaft, and it can be assumed *vice versa* that the stiffness of the shaft has been changed if the critical speed is changed.

If a rotating shaft with a negligible mass carries between two bearings a load of the mass m and of a slight eccentricity e, and if its stiffness is called k_1, the critical speed is

$$\omega_1 = \sqrt{\frac{k_1}{m}}.$$

If the shaft is surrounded by a tight concentric hollow shaft of the stiffness k_2, the critical speed is

$$\omega_2 = \sqrt{\frac{k_1 + k_2}{m}}.$$

To apply these results to the shaft under consideration, the first case can be related to the assumption of loose bushes, and the second to the assumption of tight bushes. The actual fit is neither quite loose nor absolutely tight, and the siffness depends on the deflection of the shaft under the mass m, k approaching k_1 for small deflections, and k_2 for large deflections. It can thus be assumed that the function of the stiffness k is of the form

$$k = k_1 + \frac{k_2\, y^n}{a + y^n},$$

wherein $n > 1$, and a is a large value because the reinforcing influence of the hollow shaft is noticeable only

(*Concluded on page* 102)

Maximum Heat Transfer to Boiling Water at High Pressures

By E. A. KAZAKOVA. (From *Izvestia Akademii Nauk SSSR*, No. 9, September 1950, pp. 1377-1387, 11 illustrations.)

The heat transfer from a platinum wire heated by alternating current to boiling water is described. The pressures used range from 1-200 *atmospheres. The apparatus used as well as the experimental method and the nature of the measurements taken are described in detail. The results are illustrated by curves and final conclusions are given in the last paragraph.*

WHEN boiling liquids, as the heat intensity at the heated surface increases, the number of vapour bubbles formed becomes important inasmuch as the usual form of bubble-boiling is superseded by so-called " film boiling " which is characterised by the appearance on the heated surface of a continuous layer of vapour. With the appearance of such a layer, access of the liquid to the heated surface ceases and the intensity of heat exchange falls rapidly.

Experiments at atmospheric pressure showed that during the transition from bubble-boiling to film boiling the decrease in the magnitude of the coefficient of heat transfer is of the order of several decimal places. This decrease in the intensity of heat exchange, in spite of the possible decline in surface efficiency, can cause a prohibitive increase in wall temperature. Therefore, to ensure good heat transmission at the heated surface, it is necessary to avoid conditions leading to the film boiling state.

It has many times been shown that the transition from bubble-boiling to film boiling at atmospheric pressure occurs at a certain heat transfer and temperature difference between the heated wall and the boiling liquid. This heat transfer is called the " maximum or critical heat transfer q_{max}." The value of the critical heat transfer depends on the physical properties of the liquid and a number of other factors, the most important of which is the variation in pressure.

An investigation carried out by the author[1] in 1945-46 showed that by increasing the pressure to about one third of the critical value, a considerable increase of q_{max} is observed (3-4 times).

In the work of S. S. Kutateladze[2] carried out at a pressure of 20 atm on graphite plates heated by an electric current, a considerable increase of q_{max} was noticed. Similar results were obtained by Cichelli and Bonilla[3] with organic substances; experimental difficulties prevented them from obtaining suitable results with water.

In our first investigation it was possible to obtain pressures up to 115 atm, and it was noticed that from about 80 atm onward q_{max} began to decrease.

The use of high pressure and extra-high pressure boilers requires a knowledge of transition from bubble-boiling to film boiling in the region of 100-200 atm, especially since the decrease in value of q_{max} observed for pressures above 80 atm led to the supposition that it would further decrease at higher pressures. This supposition was proved to be true by experiments carried out by S. M. Lukomski[4] with boiling carbonic acid at high pressures almost reaching the critical value.

The work described in the following paragraphs was an experimental determination of the conditions under which film boiling of water at pressures of 1-200 atm is obtained[8].

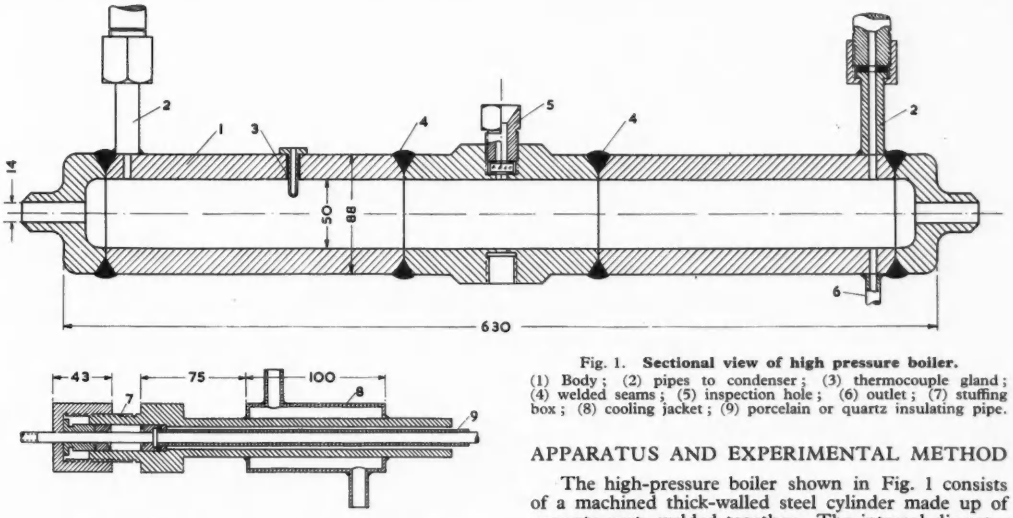


Fig. 1. Sectional view of high pressure boiler.
(1) Body; (2) pipes to condenser; (3) thermocouple gland; (4) welded seams; (5) inspection hole; (6) outlet; (7) stuffing box; (8) cooling jacket; (9) porcelain or quartz insulating pipe.

APPARATUS AND EXPERIMENTAL METHOD

The high-pressure boiler shown in Fig. 1 consists of a machined thick-walled steel cylinder made up of separate parts welded together. The internal diameter of the cylinder is 50 mm and its total length 600 mm. It was provided with an inspection hole, which could be used up to 100 atm. The heating surface on which the boiling process took place consisted of a horizontally stretched wire of 0·15 mm dia. carrying electric current. The electrodes were introduced into the apparatus through glands provided with water cooling to keep the rubber packings at normal temperature. To avoid short-circuiting, the electric leads were enclosed in porcelain or quartz tubes. The electrode ends inside the apparatus were fixed to a special insulator, to which also the platinum wire was attached. To compensate for temperature deviations, a telescopic mechanism with a spring coupling on one of the leads was provided.

The vapours formed were condensed in the condenser, and the condensate flowed back into the boiler. The left-hand part of the condenser, in which the

vapours rise was fitted with an electric heater, and the right-hand part with a cooling jacket. The boiler and the condenser were previously pressure-tested at 300 atm, which enabled tests with water to be carried out up to the critical pressure (225·5 atm).

To reach the necessary pressure quickly and to avoid escape of heat into the surrounding medium, the high pressure apparatus was covered with a cylindrical metal tank provided with mica insulation, over which an electric heater winding was provided. Thermocouples attached to the pressure parts of the apparatus at various points and to the external cover made it possible to maintain the required pressure with sufficient accuracy. The whole lay-out was provided with good heat insulation. For the purpose of determining the boiling temperature of water, the apparatus was provided with a welded socket, in which a thermocouple was inserted. The working range of the condenser was observed by means of thermocouples fixed to the walls of pipes connecting the condenser with the boiler. The temperature was determined by means of a potentiometer, permitting a reading accuracy of 0·5° C.

To avoid corrosion and the electrolytic deposition of copper on the surface of the wire, alternating current was used in this work. However, this made electrical measurements much more difficult.

The measurements to be made consisted in measuring the consumption of electrical energy and in recording the variation of wire resistance for the purpose of measuring the temperature increase taking place in conjunction with an increase in the rate of evaporation.

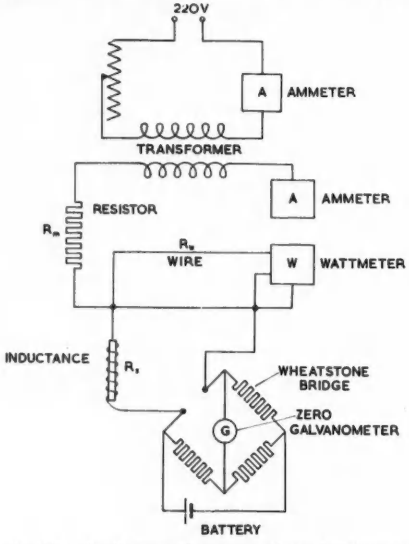


Fig. 2. **Circuit diagram for measuring wire temperature and heat transfer.**

The experimental installation[9] is shown schematically in Fig. 2. According to this scheme, the heating wire was passed simultaneously by the a.c. heating current of 20 A and by a measuring d.c. current of about 0·1 A. In order to prevent the a.c. flowing into the d.c. circuits, the bridge included an inductance coil with a sufficiently high reactance.

However, to determine the heater wire resistance R_w, it was necessary to maintain constant the d.c. resistance in the a.c. circuit. A transformer was therefore included and the current-regulating rheostats were placed on the primary side so as to ensure constant resistance in the secondary circuit, which included the heating wire element. To minimise the influence of small changes in resistance of the connections, and in order that the bridge should respond more readily to the changes in the heater wire resistance R_w, a sufficiently large additional manganin resistor R_m was connected in the secondary a.c. circuit.

The required resistance R_w was found from the formula

$$R_w = \frac{R_{tot} - R_s}{1 - \dfrac{R_{tot} - R_s}{R_{sc}}}$$

where R_w = resistance of heater wire;
R_{tot} = total resistance of the branched-off circuit as measured by the bridge;
R_s = resistance of inductance coil including leads;
R_{sc} = sum of resistance in secondary circuit, including additional resistance, transformer, instruments, and leads.

The change in wire resistance was a measure of temperature. The changes in resistance were measured by means of a Thomson bridge. The heat flow was found from the dissipation of electrical energy

$$q = \frac{0{\cdot}86\, I^2 R_w}{\pi\, d_w L_w} \quad [\text{kcal/m}^2\,\text{hr}]$$

where I = current in A;
d_w = heater wire dia. in metres;
L_w = heater wire length in metres.

In the calculations, a correction for the electrical conductivity of water had to be taken into account. This correction under high temperature conditions is of importance, as the water forms an electrical circuit in parallel with the heater wire.

The correction was determined, on the basis of deviations of the temperature coefficient of resistivity of a standard platinum wire heater placed in the boiler (at various temperatures), from the nominal value of the coefficient for platinum. This correction changed the value of heat transfer by 5-10 per cent.

The dissipation of electrical energy was measured by means of an ammeter and a voltmeter with an accuracy of 0·5. The wire diameter was measured by means of a micrometer with an accuracy of 0·005 mm and was checked a few times with a microscope. The length of the wire was measured with an accuracy of 0·5 mm. The tests were made with distilled water.

TEST RESULTS

About 43 tests at various pressures were made; 20 at pressures up to 100 atm, and 23 at pressures of 100-200 atm. Special attention was given to the range 170-200 atm, as being the most interesting from the point of view of extra-high pressure boilers. At these pressures, 12 tests were made, which gave consistent values of q_{max}.

The tests were divided into two groups:

(1) Tests carried out at pressures of 1-64 atm, in which the surface of the platinum wire remained clean and polished during the experiment.
(2) Tests carried out at 90 atm and above, in which there was some heat corrosion and salt deposition visible on the wire surface.

X-ray analysis showed that these deposits were amorphous silicon compounds formed at high pressures from the porcelain and quartz tubes used for the insulation of leads in the boiler.

Tests carried out at atmospheric pressure have shown that changes in the condition of the heating surface caused by corrosion and various deposits (deposits of salts, electrolytic deposition of copper) have an

important influence on the value of q_{max} and, as compared with the values obtained with pure metals, this always increases. It was, therefore, to be expected that with the appearance of deposits, q_{max} would increase sharply.

In order to obtain comparable results with both groups of tests, a piece of the wire covered with deposits was placed in a glass boiler, and, at atmospheric pressure, q_{max} for a given surface was determined. A graph was then drawn, in which, as ordinates, the ratio of q_{max} for a given pressure divided by q_{max} corresponding to atmospheric pressure was plotted.

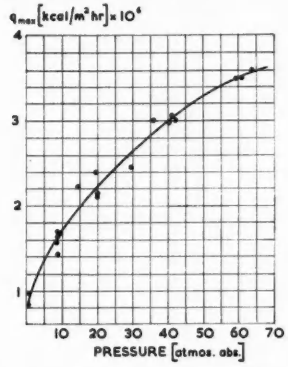


Fig. 3. **Graph illustrating the relationship between q_{max} and pressure.**

Fig. 3 shows the results obtained with pure platinum wire. The deviation of some of the points from the curve drawn does not exceed a few per cent. The figure shows quite clearly that within the tested range (i.e., up to 65 atm), a considerable increase of q_{max} is observed, but the rate of increase falls off as the pressure rises. At pressures of about 60 atm, q_{max} reaches 3,500,000 kcal/m² hr, which is four times the maximum heat transfer at atmospheric pressure. At pressures of the order of 90 atm and a heat dissipation of the order 3,000,000-3,500,000 kcal/m² hr, the deposition of difficultly soluble substances was noticed on the wire. This could be observed from the rapid increase in temperature of the heater wire. Deposits of 0·001 mm thickness were already observed by bridge measurement.

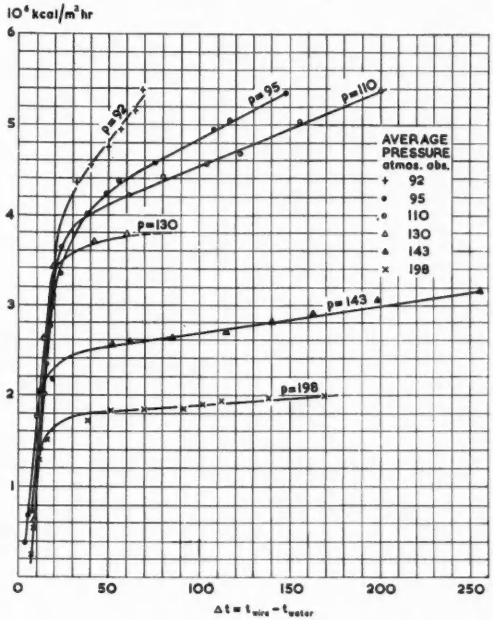


Fig. 4. **Heat exchange to boiling water at high-pressure associated with salt deposit on heated surface.**

It was found that the thickness of the deposit increases considerably with the increase in pressure. Thus, for example, in tests at 90-100 atm, the thickness of deposit at the moment the wire melted (about 10 minutes) was 0·01 mm; at $p = 145$ atm, during the same time, this thickness was 0·04-0·05 mm, and for $p = 180$-190 atm, the thickness reached 0·1-0·15 mm. At the same time it was noticed that as the pressure increases, the salt deposition starts sooner, i.e., at lower heat transfer values.

Fig. 4 represents curves of $q = f(\Delta t)$ under conditions of salt deposition on the wire surface. The curves shown in this illustration are qualitative characteristics of the observed process. The calculation of the heat transfer values was based on the increase in area of the heating surface caused by the deposits. The diameter of the wire ($d = 0{\cdot}15$ mm) covered with deposits was measured by a micrometer with an accuracy of 0·005 mm.

From the graph it is seen that, with the increase of pressure, the deviation of the curves indicating salt deposition starts at lower heat transfer values. Thus, if, at $p = 92$ atm, the deviation of the curve started at a heat transfer of the order of 3,500,000 kcal/m² hr, at $p = 110$ atm this happens at $q \approx 3{,}000{,}000$ kcal/m² hr; at $p = 143$ atm, $q = 2{,}000{,}000$ kcal/m² hr and, finally, for $p = 198$ atm, the curve changes direction at 1,200,000-1,400,000 kcal/m² hr.

With the rise of pressure, the curves change rather more abruptly, which indicates the increase in intensity of deposition. This is also proved by the thickness of the deposits as measured after the tests.

However, considering a comparatively short time interval during which the test took place, there is not sufficient reason to believe that the deposition at a given pressure will not start at lower values of heat transfer if the duration of the tests were increased.

The measured values of q_{max} obtained on wires covered with salts are given in Fig. 5.

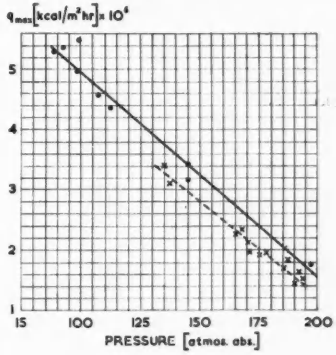


Fig. 5. **Relationship between q_{max} and pressure.**

Data obtained from tests with porcelain insulators are shown by dots, and those for quartz by crosses. Deposits obtained in the two cases also differed in external appearance from each other. In the case of porcelain, the deposit had a coarse structure, whereas quartz produced a deposit having a smooth and glassy

structure, sometimes lustrous on fracture. Absolute values of q_{max} obtained with quartz insulators were somewhat lower.

The results obtained show quite clearly that the value of maximum heat transfer always decreases with rise of pressure above 90 atm; it decreases 3-3½ times as compared with that at a pressure of 90 atm.

In Fig. 6, results of the two groups of tests are illustrated, i.e., both for a clean heating surface and for one polluted by salt deposits. Both branches of the curves are in complete agreement with each other, giving a clear maximum for a pressure of the order 65-90 atm. At pressures of 180-190 atm, q_{max} falls to a value corresponding to atmospheric pressure.

Even at this stage it is possible to compare the available experimental data on the influence of pressure on q_{max} and to judge how satisfactorily the theoretical equations suggested by S. S. Kutateladze[2] and G. N. Krushilin[7] agree with practical results.

This comparison is made in Fig. 7. Data given by Farber and Scorah, in view of the small range of pressures at which tests took place, were difficult to represent with other results and, therefore, they are shown separately in Fig. 8. In this figure the author's results for platinum wire are also given. In Fig. 9, the author's results for water are shown, together with the theoretical curve of Cichelli and Bonilla as obtained for organic compounds.

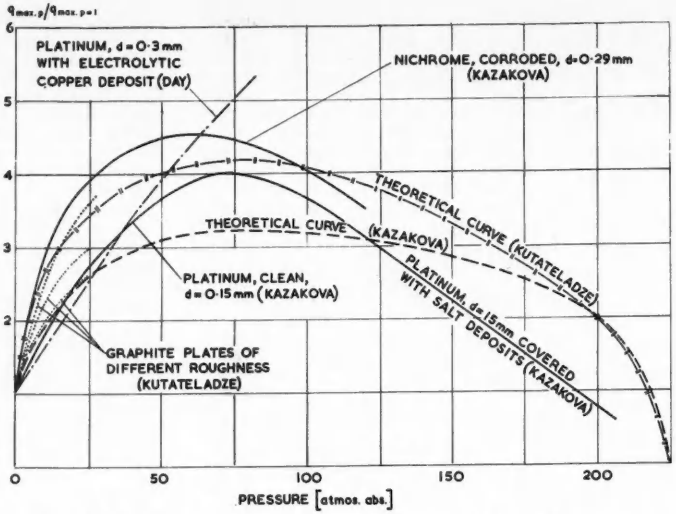

$q_{max.p}/q_{max.p=1}$
PLATINUM, d = 0·3 mm WITH ELECTROLYTIC COPPER DEPOSIT (DAY)
NICHROME, CORRODED, d=0·29 mm (KAZAKOVA)
THEORETICAL CURVE (KUTATELADZE)
THEORETICAL CURVE (KAZAKOVA)
PLATINUM, CLEAN, d = 0·15 mm (KAZAKOVA)
PLATINUM, d=15mm COVERED WITH SALT DEPOSITS (KAZAKOVA)
GRAPHITE PLATES OF DIFFERENT ROUGHNESS (KUTATELADZE)
PRESSURE [atmos. abs.]

Fig. 7. **Graph showing the ratio $q_{max\,p}/q_{max\,p=1}$ plotted against pressure, according to various investigators.**

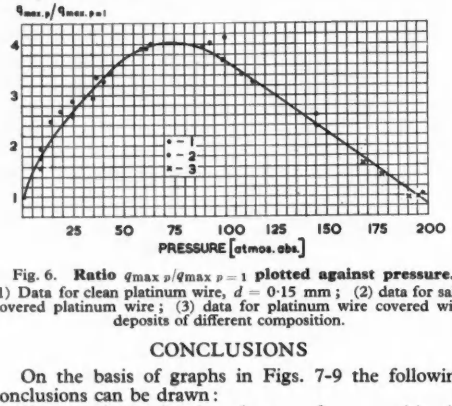


Fig. 6. **Ratio $q_{max\,p}/q_{max\,p=1}$ plotted against pressure.**
(1) Data for clean platinum wire, $d = 0{\cdot}15$ mm; (2) data for salt-covered platinum wire; (3) data for platinum wire covered with deposits of different composition.

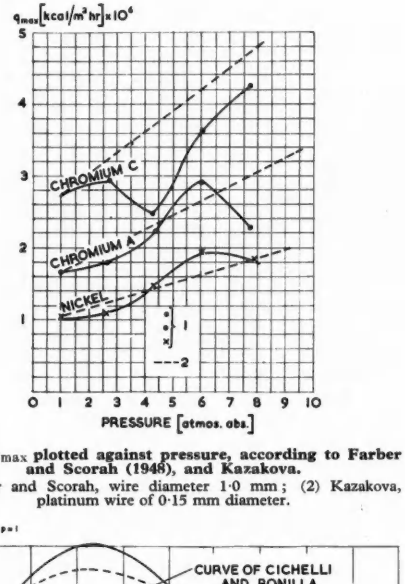


Fig. 8. **q_{max} plotted against pressure, according to Farber and Scorah (1948), and Kazakova.**
(1) Farber and Scorah, wire diameter 1·0 mm; (2) Kazakova, platinum wire of 0·15 mm diameter.

CONCLUSIONS

On the basis of graphs in Figs. 7-9 the following conclusions can be drawn:

1. The regularity in the change of q_{max} with the increase of pressure with boiling water satisfactorily agrees with results obtained when boiling organic compounds.
2. A large part of the experimental results shows that the maximum heat transfer q_{max} increases 3·5-4·5 times as compared with that at atmospheric pressure by increasing the pressure to one third of the critical value, and then quickly falls, reaching at 200 atm 0·8 of q_{max} obtained at atmospheric pressure.
3. Results obtained earlier by the author on a corroded surface and also results of S. S. Kutateladze with graphite plates of various roughness show that the microstructure of the heating surface within the range of the tests has an important influence on the value of q_{max} (variations up to 30 per cent).

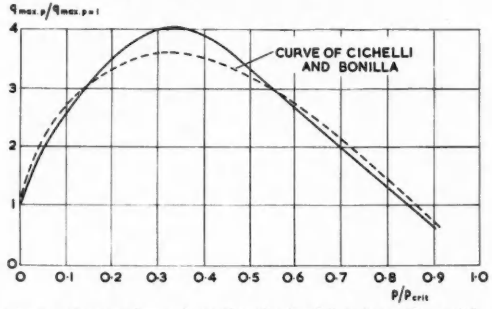


Fig. 9. **Comparison of results obtained by the author with those of Cichelli and Bonilla for organic compounds.**

It is possible that the discrepancies in the available data depend on the geometrical dimensions of the tested surfaces. It is also necessary to make a special investigation into the influence of the factors mentioned and of others on the value of q_{max}.

4. The theoretical equations produced by S. S. Kutateladze and G. H. Krushilin agree quite well, in first approximation, with experimental data in the region of growth of q_{max}, but they diverge considerably for high pressures.
5. Test results of boiling water under pressure published in the U.S.A. in 1948[5, 6] seem to be only first attempts with a comparatively small range of pressures. Their reliability is rather doubtful.

REFERENCES

(1) KAZAKOVA, E. A. Influence of pressure on maximum heat transfer to boiling water in large volume, *Izvestia AN SSSR, OTN* No. 1, 1949.

(2) KUTATELADZE, S. S. Origination of film boiling under conditions of free circulation, *Kotloturbostroenie*, No. 3, 1948.

(3) CICHELLI, M. F. and BONILLA, C. F. Heat transfer to liquids boiling under pressure, *Trans. Am. Inst. Chem. Engineers*, 41, 1945.

(4) LUKOMSKI, S. M. Heat exchange with boiling carbonic acid in tubes under high pressures, *Izvestia AN SSSR, OTN*, No. 8, 1947.

(5) FARBER, E. Q. and SCORAH, R. L. Heat transfer to water boiling under pressure, *Trans. ASME*, No. 5, 1948.

(6) MCADAMS, W. H., ADDOMS, J. N., RINALDO, P. M. and DAY, R. S. Heat transfer from single horizontal wire to boiling water, *Chem. Eng. Progress* 44, No. 8, 1948.

(7) KRUSHILIN, G. H. Heat exchange from horizontal plate to boiling liquid with free convection, *DAN SSSR* LVIII, No. 8, 1947.

(8) KAZAKOVA, E. A. Maximum heat transfer to boiling water at high and extra high pressures, *DAN SSSR* LXXI, No. 1, 1950.

(9) KAZAKOVA, E. A. Determination of temperature of wire element heated by a.c., *Zavodskaya Laboratorya*, No. 3, 1950.

SWITZERLAND

Design and Calculation of Spot-Welded Joints under Static Shear Loads

By H. ZSCHOKKE and R. MONTANDON.

(From *Schweizer Archiv*, Vol. 16, No. 9, September 1950, pp. 257-271, 25 illustrations.)

Not only the shear strength of the spot weld itself but also the design of the entire joint determine the resistance to fracture which may take place in various ways. As in the design of riveted joints, the resistance to each mode of fracture can be determined and compared, and the "most economic" designs of joints found for single and double lap, single and multiple spot, welded joints. The change in strength of the material affected by the weld heat must also be considered. Design formulae established in this way are checked by extensive tests.

STRESSES and strains in a spot-welded joint loaded in shear are very complex, as indicated by the deformation of test strips (Fig. 1). They depend on width, thickness, overlap of sheet or strip, and the movement, due to progressive deformation, of the point of application of the load. Apart from shear stresses, tensile and bending stresses appear (Fig. 1b and c) and combine to maximum stresses at the circumference of the weld itself. The restriction and concentration of the flow of force (Fig. 1e) lead to transverse warping of thin strips, (Fig. 1d), and hence also to transverse stresses. The stress concentrations, the deformations depending on the shape of the welded parts, and the deflections of the flow of force are most easily taken into account by "shape coefficients" determined from extensive test series. Since the problem is so complex, we must limit ourselves to the most important special case in practice of static shearing loads acting on welded strips of equal material, width, and thickness, the spot welds being situated symmetrically about the transverse and longitudinal axes of the joints.

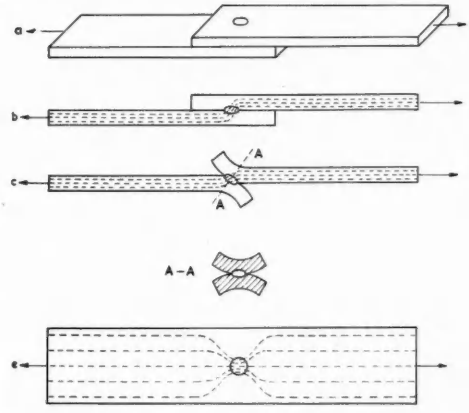


Fig. 1. **Deformation of, and flow of force in, a single lap single spot weld tension-shear test specimen.**

I. INFLUENCE OF THE MATERIAL.

Test series on various low-carbon steels show that, under normal conditions, the shear strength of the welded joint increases proportionally with the ultimate strength of the parent material[1]. Other materials, however, may harden or—if already hardened or cold-worked—may soften in the zone affected by the weld heat, and the ensuing change in tensile strength must be considered. We may assume that heating changes hardness, tensile strength, and shear strength in an analogous manner, so that hardness measurements across the welded section also indicate the changes in strength across the heat-affected zones. For a given material, we can then deduce approximate values of the two ratios.

$$c_1 = \frac{\text{hardness at centre of weld}}{\text{hardness of unaffected plate}} = \frac{\text{tensile or shear strength of centre of weld}}{\text{tensile or shear strength of unaffected plate}} \quad \text{and}$$

$$c_2 = \frac{\text{diameter of heat-affected zone}}{\text{diameter of weld proper}}.$$

c_1 slightly varies with welding conditions but is essentially constant for each material; c_2 depends on metal properties and welding conditions, such as strip thickness and electrode cooling. $c_1 > 1$ indicates a hardening, $c_1 < 1$ a softening effect, whilst $c_2 \geq 1$ under all conditions. Table 1 shows that c_1 differs for each material, but c_2 has an appreciably constant value for the steels

Table I. AVERAGE VALUES OF c_1 AND c_2 FOR VARIOUS MATERIALS, AS FOUND FROM TEST PIECES 0·04 TO 0·20 IN. THICK.

Material	c_1	c_2
Boiler plate	1·80–2·00	1·30–1·55
Deep-drawing steel sheet	1·35–1·60	1·30–1·55
18/8 stainless steel sheet	1·00–1·10	1·15–1·30
Deep-drawing steel sheet, normalized after welding	1·00	1·00
Aluminium, 99·5%, soft	1·00	1·00
Aluminium, 99·5%, hard	0·60–0·64	1·80–2·00
Al-Si-Mg alloy, semi-hard	0·60–0·70	1·70–1·90
Al-Si-Mg alloy, hard	0·56–0·62	1·70–1·90
Al-3 Mg alloy, semi-hard	0·62–0·72	1·60–1·80

and another constant value for the light alloys. For easily weldable materials with $c_1 \geqslant 1$ (deep-drawing sheet, 18/8 stainless sheet), we find, roughly, $c_2/c_1 = 1$.

In order to express all the required strength values in terms of the ultimate tensile strength of the parent plate, we finally assume

$$\frac{\text{Ultimate shear strength}}{\text{Ultimate tensile strength}} = \frac{S}{Z} = 0{\cdot}65.$$

The actual value varies between 0·57 and 0·85, according to the material. If S, Z refer to the original plate, S', Z' to the heat-affected material, we have

$$Z' = c_1 Z \text{ and } S' = 0{\cdot}65\, Z' = 0{\cdot}65\, c_1 Z \quad .. \quad (1)$$

II. SINGLE LAP JOINTS.

A. DESIGN FORMULAE AND SHAPE COEFFICIENTS.

The dimensions of a spot-welded joint influence not only the breaking load but also the mode of fracture, as shown by the fractures of three test-pieces which are identical except for their strip width (Fig. 2). Thus,

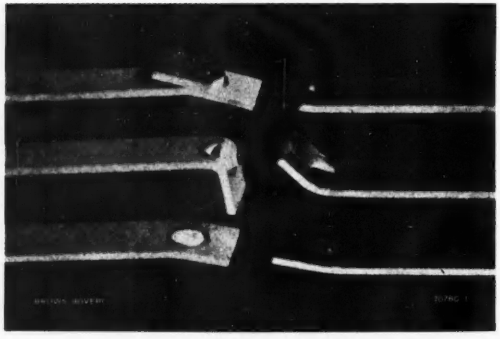


Fig. 2. **Different modes of failure obtained on specimens of various widths under otherwise identical conditions.**
Top : tensile fracture at weld,
Centre : peeling fracture of weld.
Bottom : shear fracture of weld.

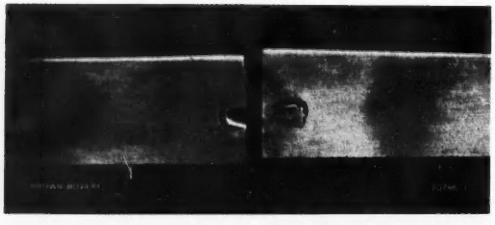


Fig. 3. **Tearing-out fracture of single lap single spot weld tension-shear specimen.**

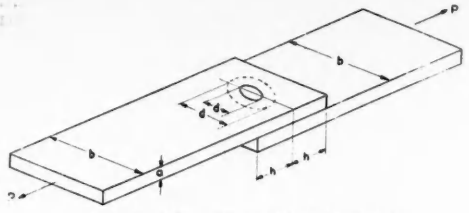


Fig. 4. **Dimensions of single lap joints.**
d = diameter of fused weld zone in the plane of contact,
d' = diameter of heat affected zone.

there exist different critical cross-sections, each one of which may, according to conditions, be the weakest. We must therefore calculate the resistance to each mode of fracture and find the lowest value. With the symbols of Fig. 4 and eqs. (1), and the shape factors K, the resistance to each mode of fracture is obtained as follows :

A. Tensile fracture of strip, away from weld. (Only occurs with " hardening " materials).
$$P_{B'} = Zab.$$

B. Tensile fracture around weld (Fig. 2, top). (Only occurs with " softening " materials).
$$P_R = Z'\, ab\, K_R.$$

C. Shear fracture (Fig. 2, bottom),
$$P_S = S' \frac{\pi}{4} d^2 K_S.$$

D. Peeling fracture (Fig. 2, centre)
for " hardening " materials,
$$P_A = Z\, ad'\, K_A,$$
for " softening " materials,
$$P_A = Z'\, ad\, K_A.$$

E. Tearing-out fracture (Fig. 3),
for " hardening " materials,
$$P_U = Zad' + Sa \,.\, 2h,$$
for " softening " materials,
$$P_U = Z'\, ad + S'\, ad' + Sa\,(2h - d').$$

Fractures A and B indicate too large a weld diameter as compared with the strip width ; the shape factors are 1 and K_R respectively. Fracture C indicates too small a weld diameter ; the factor K_S characterises the non-uniform stress distribution and depends on the dimensions of strip and joint. Fracture D shows shear as well as tension, but only the tensile stress is considered here,

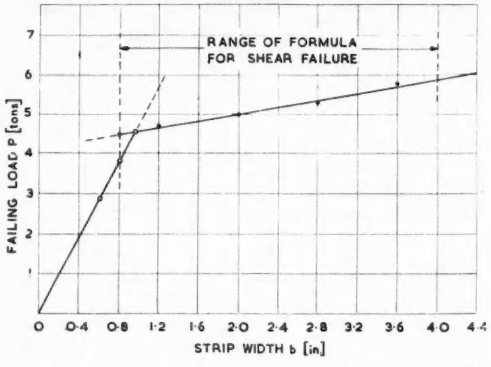


Fig. 5. **Example of test series for the determination of K_S.**
Deep-drawing steel sheet (Z = 24 tsi, c_1 = 1·55, c_2 = 1·55), a = 0·2 in., d = 0·44 in.
• = test results for shear fracture of weld,
○ = test results for tensile fracture of strip.

Table II. DESIGN FORMULAE GIVING BREAKING LOADS FOR DIFFERENT TYPES OF FRACTURES OF SINGLE AND DOUBLE LAP SINGLE SPOT WELD JOINTS BETWEEN STRIPS OF EQUAL MATERIAL (Z, c_1, c_2) AND THICKNESS a.

	Type of fracture	" Hardening " materials	" Softening " materials
Single Lap	Tensile fracture of strip, P_{Bl} =	$Z\,a\,b$	—
	Tensile fracture around weld, P_R =	—	$Z\,c_1\,a\,b$
	shear fracture, P_S =	$0{\cdot}6\,Z\,c_1\,d^2\sqrt{1+b/10d}$	
	Peeling fracture, P_A =	$1{\cdot}4\,Z\,c_2\,ad\sqrt{1+b/10d}$	$1{\cdot}4\,Z\,c_1\,ad\sqrt{1+b/10d}$
	Tearing-out fracture, P_U =	$Za\,(c_2\,d + 1{\cdot}3\,h)$	$Za\,(c_1\,d + 0{\cdot}65\,c_1\,c_2\,d - 0{\cdot}65\,c_2\,d + 1{\cdot}3\,h)$
Double Lap	Shear fracture, P_S =	$1{\cdot}06\,Z\,c_1\,d^2$	
	Peeling fracture, P_A =	$5{\cdot}84\,Z\,c_2\,ad$	$5{\cdot}84\,Z\,c_1\,ad$
	P_{Bl} and P_R as for single lap joints. P_U as for single lap joints if $h \leqslant \frac{2}{3}$		

For multiple spot joints, calculate $d = d_K$ from Table III and take $b = e$ to be the weld pitch.

the shearing part being contained in the factor K_A. Fracture E is due to too small an overlap ; no shape factor is given because the deformations remain small. The smallest breaking load P, as obtained from these formulae, determines the strength of the joint.

The K-factors can be determined by tests, for instance, on spot-welded strips of deep-drawing steel sheet, 0·02, 0·08, and 0·20 in. thick (Fig. 5) : Narrow test pieces fail in the strip, and the breaking load rises rapidly as the width is increased. Above a critical width, however, depending on thickness and weld diameter, shear and peeling fractures occur, and the breaking load rises slowly with further increasing width. All the test series exhibiting equal modes of fracture may now be taken together, and an empirical expression for the corresponding shape coefficient so found that, for the given test dimensions, the calculated lines are in close agreement with most of the test results (see Fig. 5). We thus obtain

$K_S = 1{\cdot}18\sqrt{1 + b/10d}$, $K_A = 1{\cdot}40\sqrt{1 + b/10d}$, $K_R = 1$,

and by substitution, the equations of Table II, constituting practical design formulae, although limited in application to a range of materials and thicknesses as used for the determination of the K-factors and the weld heat effects. Tests and calculations agree well for deep-drawing steel sheet, 0·02 to 0·20 in. thick, and Al-Si-Mg semi-hard sheet, but deviations are large for steel strip 0·40 in. thick. In the following, we shall therefore restrict ourselves to thicknesses of 0·02 to 0·20 in.

B. THE " MOST ECONOMIC " DESIGN OF A JOINT.

Since the overlap can hardly be smaller than $h = 3a$ if the edges are not to be squeezed out, a tearing-out fracture will be practically impossible. The breaking loads for the remaining three modes of fracture are, for a given material (Z, c_1, c_2) of given thickness a, functions of b and d only (Fig. 6). If equated, they determine values of b and d characterising the " most economic " design in which the strengths of weld cross-section, weld circumference, and parent strip are all used to best advantage (Point K, Fig. 6). If b and/or d increase above the values for point K, the breaking load rises more slowly than for values below K. Expanding the square roots of K_S and K_A, and using the first two terms only, we thus obtain the " most economic " dimensions, and the corresponding breaking load (Table III) for a given material as a function of its thickness a. Although these values are still subject to the inaccuracies and limitations caused by an empirical determination of K-factors and heat effects (c_1, c_2), a " most economic " design can always be calculated in principle.

Table III. " MOST ECONOMIC " DIMENSIONS AND CORRESPONDING BREAKING LOADS FOR SINGLE AND DOUBLE LAP SINGLE SPOT WELD JOINTS BETWEEN STRIPS OF EQUAL MATERIAL (Z, c_1, c_2) AND THICKNESS a.

		Spot dia. d_K	Strip width b_K	Breaking load P_K	Overlap h_K
Single lap	" Hardening " material $c_1 \geqslant 1$	$2{\cdot}33\,a\,c_2/c_1$	$\dfrac{3{\cdot}26\,a\,c_2}{1 - 0{\cdot}07\,c_2} \times \dfrac{c_2}{c_1}$	$\dfrac{3{\cdot}26\,Z\,a^2\,c_2}{1 - 0{\cdot}07\,c_2} \times \dfrac{c_2}{c_1}$	$\geqslant 3a$
	" Softening " material $c_1 \leqslant 1$	$2{\cdot}33\,a$	$3{\cdot}5\,a$	$3{\cdot}5\,Z\,a^2\,c_1$	$\geqslant 3a$
Double lap	" Hardening " material $c_1 \geqslant 1$	chosen as for single lap joints	$5{\cdot}75\,a\,c_2 \times \dfrac{c_2}{c_1}$	$5{\cdot}75\,Z\,a^2\,c_2 \times \dfrac{c_2}{c_1}$	$2{\cdot}63\,a\,c_2 \times \dfrac{c_2}{c_1}$
	" Softening " material $c_1 \leqslant 1$		$5{\cdot}75\,a$	$5{\cdot}75\,Z\,a^2\,c_1$	$a\,(2{\cdot}63\,c_1 - 1{\cdot}17\,c_1\,c_2 + 1{\cdot}17\,c_2)$

For multiple spot joints with n spots, choose d_K as above, take $b_K = e_K$ to be the weld pitch, and $P_{Kn} = 0{\cdot}8\,n\,P_K$.

The different modes of fracture also explain why spot-welded test pieces must be standardised. Practical standard dimensions should be slightly above the "most economic" dimensions so that, even with stray results, shear fractures with their rapidly falling strength are avoided. In fact, published proposals for standardisation [1, 2, 3] are slightly above the "most economic" dimensions and deviate appreciably only where present-day welding practice specifically demands larger dimensions.

C. Multiple spot joints.

In a row of spot welds, neighbouring spots largely limit deformations, so that peeling fractures are rare, if at all possible. The upper surface *m* of Fig. 6 then disappears and the "economic" dimensions follow the limit of equal strength against weld shear and sheet tension. Although many "economic" designs are thus possible, sound practice will usually choose a weld diameter about equal to that of the corresponding single spot joint, and a pitch *e* about equal to the "economic" strip width *b* of the single spot joint. The design formulae are then still valid if *b* is replaced by *e*.

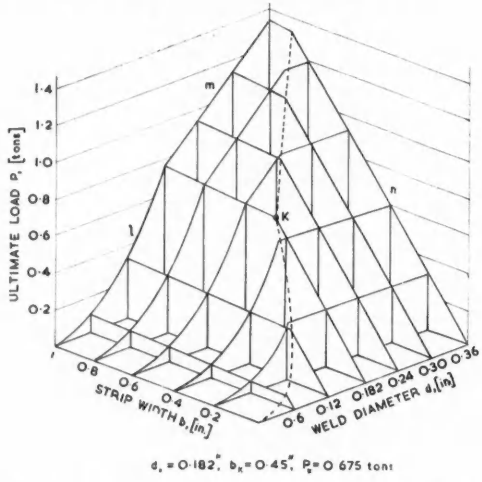


Fig. 6. ***P* as a function of *b* and *d* for deep-drawing steel sheet.**

Z = 19 tsi, c_1 = 1·55, c_2 = 1·55), a = 0·08 in., single lap joint, h = 0·24 in.

l = shear fractures, *m* = peeling fractures, *n* = tensile fractures of strip.

Important for the strength of a multiple spot joint is the *ultimate load per unit length of joint*. Test pieces with 1, 2, 3, 4 spots and different spot diameters and pitches were tested to destruction and the spot diameters then determined after grinding. For small *e*, the tensile strength of the sheet determines the fracture, so that the ultimate load per unit length remains constant. The strength of the welds is then not fully utilised. Above the "economic" pitch *e* of equal weld and sheet strength, shear fractures become prevalent and the ultimate load per unit length drops rapidly with further increasing *e* (Fig. 7). Test results are seen to agree well with design calculations from Table II. According to Table III, the "economic" dimensions for the tests of Fig. 7 are $d_K = 2{\cdot}33a = 0{\cdot}187$ in. and $e_K\ (= b_K) = 5{\cdot}66a = 0{\cdot}453$ in. U.S.A. standards[2] propose much larger pitch sizes for multiple spot welds and, therefore, lead to serious losses of utilisable strength or to uneconomically large spot diameters. Other proposals[1], however, suggest pitch sizes in close agreement with e_K.

Fig. 7, finally, shows that the strength per unit length

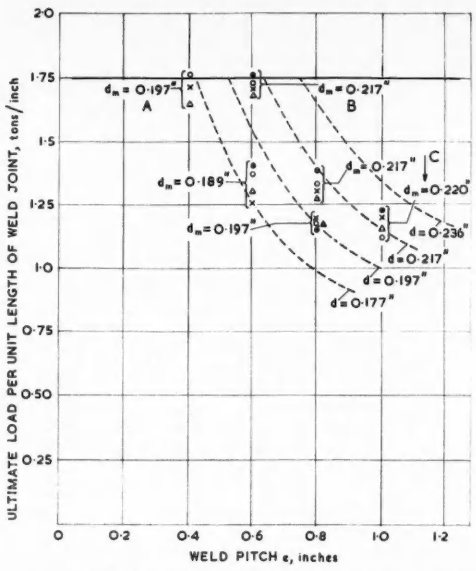


Fig. 7. **Ultimate load per unit length as a function of the spot weld pitch in single lap multiple spot weld joints of deep-drawing sheet steel of a = 0·08 in. thickness.**

Z = 22 tsi, c_1 = 1·55, c_2 = 1·55. The curves represent calculated results. *A* = region of tensile fractures of sheet, *B* = region of tensile and shear fractures, *C* = region of shear fractures of welds, • = test pieces with 1 spot weld, ○, ×, Δ = test pieces with 2, 3, 4 spot welds respectively.

decreases with increasing number of spot welds in the test specimen. The strength of the single welds can apparently not be fully utilised, and an "efficiency" factor η must be introduced. Although η = 0·90 to 0·95 in Fig. 7, the greater number of spot welds in practical joints will probably reduce η. Values of 0·80 to 0·90 have been suggested in American literature.

III. Double lap joints between sheets of equal thickness.

In double lap joints (Fig. 8), the deformations, heat influences, and modes of fracture are similar to those of single lap joints, so that similar fundamental equations

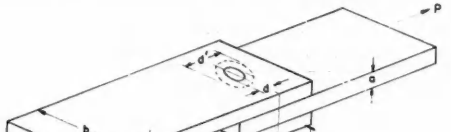


Fig. 8. **Dimensions of double lap joints.**

d = mean value of weld diameters in the two planes of contact, h = 2/3 u for equal resistance of all strips against tearing-out fracture.

can be established. The tensile strengths $P_{B'}$ and P_R are the same as for single lap joints because fracture can only occur in the middle strip; irregular deformations are insignificant, so that $K_R = 1$. $P_S = 2\,S'\,K_S\,d^2\,\pi/4$ since two weld cross-sections resist the shearing action, and from tests, K_S = const. = 1·04. Two cross-sections also resist peeling fractures, and K_A = const. = 2·92 from published test results[4]. If, lastly, we assume

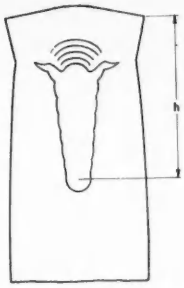


Fig. 9. **Combined tearing and peeling fracture occurring when $h/a \geqslant 10$.**

$h = 2/3\ u$, P_U is also the same as for single lap joints. The final design formulae are again given in Table II.

The failing loads of double lap spot welds are much larger than those of single lap welds. h must, therefore, be chosen larger than $3a$, but if it is too large, the two shear cross-sections may not be stressed equally, and combined fractures (Fig. 9) may occur[4] for $h \geqslant 10a$. The design formulae are, therefore, valid only for $h \leqslant 10a$. They are also limited in application for the reasons already stated. The " most economical " point of equal strength is seldom reached in practice, as the outer strips rarely bend far enough for peeling fractures to occur. An " economic " design will therefore follow the curve of equal shear and tensile strengths. The weld diameter is then usually chosen equal to the " economic " weld diameter of the corresponding single lap weld. The " economic " strip width b_K, overlap h_K, and ultimate load P_K are thus fixed (Table III). The increase in " economic " width, or the gain in breaking strength, as compared with single lap spot welds, is only about 60 per cent because the possible deformations are so much smaller. The results may be extended to multiple spot welds in a similar manner as before, with the same limitations and efficiency factors. Under otherwise identical circumstances, the pitch of double lap spot welds is 60 per cent larger than that of single lap spot welds of the same strength.

IV. CONCLUSIONS.

The design formulae of Tables II and III permit of calculating the strength of a given spot-welded joint, or dimensioning of an " economic " joint for a given static shear load. They may be evaluated in the form of numerical tables for specific practical examples, and the calculated dimensions adapted to current welding practice. The weld diameter d is fixed first, and the strip width b, or pitch e, so determined that single spot welds just fail at the weld, multiple spot welds in the sheet. The type of fracture in single lap single spot welds then characterises already the correct diameter d : shear fractures denote too small a weld diameter, strip fractures too large a weld diameter, and peeling fractures the correct diameter. However, welding practice requires that $d \geqslant 0{\cdot}1$ in., $b \geqslant 0{\cdot}312$ in., and, for double lap joints, $u - h \geqslant 3a$, so that for thin sheets, these dimensions are larger than necessary from strength considerations. The calculated strength and mode of fracture also provide a check on the quality of welding. Within the limitations and range of applications already indicated, the calculations were found to agree well with the results of 54 tests on single lap (single and multiple spot) and double lap (single spot) welds. The deviations were $\pm$ 3·3 per cent on the average, $\pm$ 9 per cent maximum, i.e., within the stray range of a carefully welded multiple spot joint.

BIBLIOGRAPHY.

(1) HEUSCHKEL, Selecting Spot Welding Schedules for Low Carbon Steels, *Welding Journal*, October, 1946.

(2) Tentative Standards and Recommended Practices and Procedures for Spot Welding of Aluminium Alloys, *Trans. Inst. Weld.*, 1942, No. 4.

U.S.A. Standard Proposals for Spot Welding of Low Carbon Steels, *Welding Journal*, August, 1944

(3) HIPPERSON, *Trans. Inst. Weld.*, April, 1947.

(4) Electric Resistance Welding, *Publications of Brussels Univ.*, Bulletin No. 2, 1939.

SWEDEN

The Compressibility of Iron Powder

By J. HEUBERGER. (From *Acta Polytechnica*, Transactions of the Chalmers University of Gothenburg, No. 98, 1950, pp. 11-20, 2 illustrations.)

A rational formula for the relationship between die pressure and density of the compressed powder is developed, compared with existing formulae, and tested by evaluation of experimental data.

COMPLICATED metallurgical phenomena occur when work-hardening metal powders are compacted. Even if the powder consisted only of spherical particles of equal size, the curve representing the density of the compact as a function of the pressure applied should really show two branches : a steep line at low pressures for the material which is not yet cold-worked, and another line starting at pressures when the " cold-worked cones " inside the particles begin to contact each other and a coherent work-hardened structure starts to build up in the direction of pressing. A low-pressure compact thus appears to derive from a different powder than one compacted at high pressures. The irregularities are accentuated by the fact that, at very low pressures, changes in packing and collapse of bridges between particles are superimposed on the deformation phenomena, whilst at high pressures, the work-hardened structure also extends in directions other than the direction of pressing. Phenomena are still more complicated if the composite nature of the powder, i.e., particles of various sizes and shapes, is considered. At low pressures, for instance, the cavities then fill up more easily and the density rises even more steeply.

Nevertheless, a useful approximation is obtained from a general theoretical relationship between pressure applied and density of the compact, Fig. 1. The die is filled with powder of an " apparent density " a depending on filling conditions and the weight of the powder itself. The compact is densified by application of increasing die pressure P. Its density rises quickly at first, then more slowly, and asymptotically approaches a limiting value D_∞ for extremely high pressures. D_∞ is usually smaller than the density ρ of the solid material or, at most, reaches this value. In order to obtain an analytical expression for the compacting process, we may assume that, at a given pressure P, the increase dD in density, for a very small pressure change dP, is proportional to the remaining possible range of densification, i.e., to $D_\infty - D$. Thus,

$$\frac{dD}{dP} = k'(D_\infty - D).$$

Integrating this equation and considering that for $P = 0$ the density D must equal the " apparent powder density " a, we obtain

$$kP = \log \frac{D_\infty - a}{D_\infty - D} \quad .. \quad (1)$$

D, P, and a can be measured. From a number of tests, we can then draw a curve similar to Fig. 1, thus obtaining a first approximation to the value of D_∞ and, by trial and error, improve on it so that the coefficient k of eq. (1) is, in fact, constant for the entire test series on a given metal powder.

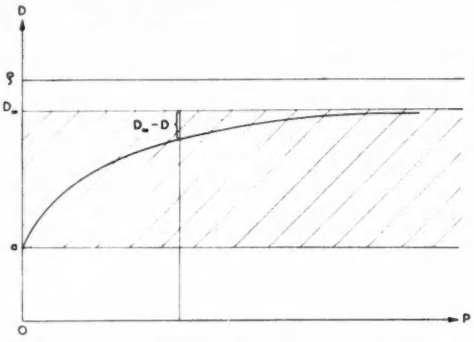


Fig. 1. **General theoretical relationship between pressure P and specific density D of metal powder compacts. The shaded area $D_\infty - a$ is the " compressibility range."**

In place of eq. (1), Konopicky[1] proposes

$$P = A \log (V_0/V_p) \quad .. \quad (2)$$

where A is a constant, V_p the degree of porosity of the compact at a pressure P, and V_0 the extrapolated corresponding value for $P = 0$. Since the degree of porosity equals

$$\frac{\text{Vol. of cavities}}{\text{Vol. of compact}} = 1 - \frac{\text{metal volume}}{\text{compact volume}} = 1 - \frac{D}{\rho},$$

we find that

$$V_p = \frac{\rho - D}{\rho}, \; V_0 = \frac{\rho - a}{\rho}, \text{ and } \frac{P}{A} = \log \frac{\rho - a}{\rho - D}.$$

Eq. (2) is thus identical with eq. (1) except for the assumption $\rho = D_\infty$, which is not always justified and explains why eq. (2) is less accurate an interpretation of the test results than eq. (1). Another empirical formula used by G. B. Smith[2],

$$D - a = C \sqrt[3]{P} \quad .. \quad .. \quad (3)$$

cannot be accurate since, for infinite pressures, it postulates an infinite density of the compact. In fact, even reasonably high pressures would increase the density of the compact beyond that of the solid metal, if this formula were correct.

The correctness of eq. (1) was checked by evaluation of the test results obtained by Smith[2], as also by specially conducted tests with a 50-mesh powder type H 50, of Swedish iron, magnetically purified, and annealed in dry hydrogen at 700° C until the weight remained practically constant. The only remaining important impurity was 0·18 per cent SiO_2, which was present partly as quartz particles of larger size, and partly as quartz dust. The tests were taken at room temperature on a hydraulic press, the die being filled level with the powder. The compact formed a ring of 1·77 in. outside dia., 1·45 in. inside dia. and about 0·32 in. width. The average

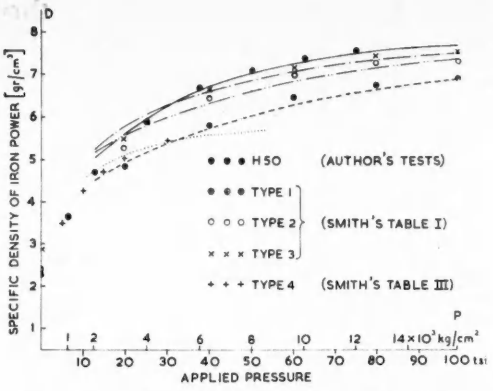


Fig. 2. **Specific density of an iron powder compact as a function of the applied pressure. Test results.**

result of at least ten tests was used for evaluation. Fig. 2 shows the results of these tests, the results evaluated from Smith's tests, and the curves calculated from eq. (1) in the manner described. The test results for low pressures are seen to be consistently below the calculated values, partly because of the irregular compacting phenomena occurring at low pressures, and partly because an accurate estimation of a is very difficult. The standard methods of measuring powder packing densities require different conditions of filling from those conveniently used for filling the test dies. Nevertheless, the curves of eq. (1) follow test results more closely than those of eqs. (2) and (3).

TABLE I.—CHARACTERISTIC VALUES OF IRON POWDERS TESTED (see Fig. 2). D_∞ AND k CALCULATED FROM eq. (1).

Powder	a	D_∞	$D_\infty - a$	$k \times 10^2$
1	2·3	7·1	4·8	1·53
2	2·5	7·45	4·95	1·85
3	2·9	7·70	4·8	1·73
4	2·41	5·91	3·5	3·31
H 50	2·35	7·85	5·5	1·91

A comparison of the characteristic values of the different iron powders (Table I) shows at once that Type 4 does not fit in with the other powders. It may have contained oxides, or substantial impurities, or an unfavourable particle shape and mesh size. Leaving Type 4 aside, we see that the coefficient k varies but slightly for different powders. Only extensive tests could reveal whether these slight differences do, in fact, characterise the comparative compressibility of various powders. Moreover, no agreed definition of compressibility yet exists. Not only should the powder reach a high density under relatively low pressures, but it should also show a certain strength for a given density, and a single factor could hardly cover these different requirements. The apparent powder density a is important as a criterion of the initial filling space, and the limiting density D_∞ indicates whether a particular powder is suitable for the manufacture of compact parts. Finally, the compressibility range $D_\infty - a$ may characterise, in some manner, the practical compacting qualities of a powder. a and, to a lesser degree, D_∞ depend on powder particle shape and mesh analysis, the effects of which cannot yet be summarised in terms of unique mathematical coefficients.

REFERENCES

(1) KIEFFER and HOTOP, Sintereisen und Sinterstahl, Vienna 1948, p. 126.
(2) G. B. SMITH, Proc. Fourth Ann. Spring Meet., Metal Powder Ass., New York 1948, p. 29.

Further Development of the NBS Magnetic Fluid Clutch

(From Technical Report 1493 of the *National Bureau of Standards*, Washington, 10 pages, 13 illustrations.)

Since this clutch was originally developed by the National Bureau of Standards in 1948, *its unique features have made it the subject of extensive investigation in both Government and industrial laboratories. As a result, valuable information has been obtained on a number of problems, such as heat dissipation, settling of the magnetic powder, and hermetic sealing, which are important in industrial applications of the clutch. At the same time, the basic principle of the magnetic fluid clutch is being utilised to make possible other significant developments in science and industry.*

THE Magnetic Fluid Clutch* is based on the discovery that the frictional forces between solid surfaces and certain types of fluid media can be controlled by the application of magnetic fields. In its simplest form, the device consists of two parallel magnetic plates separated by a powder composed of finely divided magnetic particles. When a magnetic field is established between the two plates, the magnetic particles bind the plates against movement parallel to their surfaces.

The magnetic particles may be finely divided iron, which, for most applications, is mixed with a liquid such as oil, to prevent packing and to afford smoother operation. When a portion of this mixture is acted on by a magnetic field, the iron particles are mutually attracted, bind together in the field, and the mixture seemingly solidifies. As slipping occurs only between extremely fine iron particles and between the iron particles and the smooth face surfaces of the clutch, and as all surfaces are lubricated, practically no wear occurs in the clutch.

Early in the development of the magnetic fluid clutch, it was recognised that lubricants other than oil could be used with magnetic powders to give the desired results and that the clutch could even be operated entirely without lubricant. It was suggested that graphite or other dry lubricants such as talc or molybdenum might be used, and tests showed that these materials were satisfactory. Heavy grease lubricants have also been suggested for this purpose, and so far approximately 300 lubricating mixtures of all kinds have been tested.

HEAT DISSIPATION

Dissipation of the heat produced by slippage is one of the most serious problems in all types of clutches and brakes. While air or liquid cooling can, of course, be used in the magnetic fluid clutch, special devices such as heat exchangers have been constructed and have proved satisfactory. Improved methods of sealing permit operation at high temperatures, which enable the clutch to dissipate heat at a faster rate.

An investigation of the thermal conductivity of magnetic fluids was carried out with carbonyl iron powder " E " (experimental lot, with small particles removed) in USP light mineral oil. Two thousand eighty grams of iron powder were suspended in 300 grams of oil, giving approximately a 7 to 1 mixture. Four drops of polyethylene glycol oleate were added as a wetting agent. The equipment used did not permit very high flux densities, the highest being about 3400 lines per square inch. In the temperature range from 56° to 70° F, it was found that approximately 5 B.Th.U. were conducted per square foot of cross-section per degree Fahrenheit per inch of path length. This heat conductivity value is not affected materially by higher flux densities.

If a liquid lubricant is used with the magnetic powder, the mixture itself can serve as a cooling medium when the clutch is demagnetized. The lubricant can be pumped throughout the clutch so that the heat is carried away from the working gap, where it is generated, and is dissipated through the body and the shafts of the clutch. When the mixture is strongly magnetised, however, the iron particles are not mobile and it is not possible to circulate the oil through the particles freely if the quantity of iron is appreciable. This difficulty has been overcome by pumping the excess lubricant through special passages without carrying the iron powder. Centrifugal force and magnetic attraction have been used to separate the iron from the coolant.

The use of solid lubricants such as graphite has enabled some workers to operate the clutch at higher temperatures than could be maintained with oils without pressure seals. Here, dissipation of heat is facilitated by the higher operating temperature of the clutch, which permits more rapid transfer of heat to the cooler surroundings.

SEALING

Several schemes have been used to keep the iron powder and the lubricant in the clutch cavity. One obvious method of doing this is to arrange the clutch in such a manner that no shaft seal is required. If the clutch is mounted vertically, for example, its lower part can be so enclosed that gravity will maintain the particles where they belong. However, this vertical type of mounting imposes limitations which are not always acceptable. Also, the stirring of the material is more difficult than in a clutch where the shaft is horizontal. In any case, an open clutch is desirable only when the temperatures are low and where the " breathing " of air is limited.

Labyrinth seals have been employed with varying degrees of success. If the speed of the clutch is always high, the labyrinth can be made quite effective by utilising the centrifugal forces on the powder. Where the speeds are variable and the positions of the clutch are undetermined, as in some military airborne applications, the use of labyrinths has not proved satisfactory. Labyrinths, moreover, do not prevent breathing. Thus,

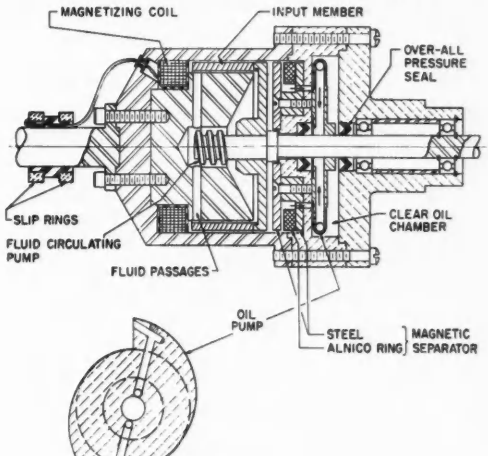


Fig. 1. **Detailed drawing of the new hermetic seal.**

* See "A Magnetic Fluid Clutch," *The Engineers' Digest*, August, 1948, pp. 260-261.

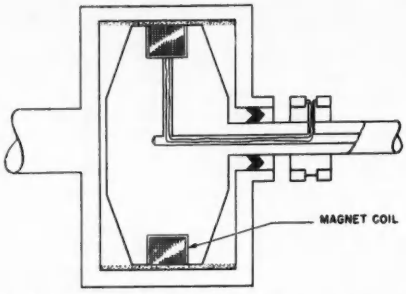


Fig. 2. **The effect of centrifugal force on the magnetic particles is minimised by using only enough iron powder to fill, or not quite fill, the working gap between the cylinders.**

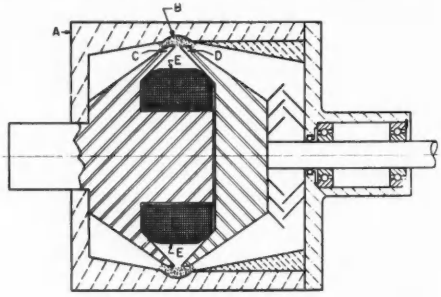


Fig. 3. **Diagrammatic arrangement of high-speed magnetic fluid clutch.**

The outside case (A) is made of non-magnetic material, and the working gap is concentrated in the small space (B), external to the pole pieces (C and D) of the driving and driven members. The clutch is excited by the coil (E).

as the clutch warms up, air is driven out, and as the clutch cools, cold air enters again, carrying with it fresh oxygen and moisture, which corrode the internal parts of the mechanism and the iron powder.

For these reasons, hermetic sealing appears to be most desirable. A satisfactory hermetic seal consists of a reservoir of clear oil, mounted adjacent to the clutch proper, so designed that the clear oil is continuously pumped along the shaft into the interior of the clutch. The clear oil is then returned to the reservoir through a magnetic separator which prevents iron particles from flowing with the oil. The magnetic separator consists of a ring magnet of Alnico having a very short air gap. The iron powder does not pass the air gap, while the oil does so quite freely. An impeller-type pump then recirculates the oil back through the shaft seal. The whole system is provided with a second seal which operates entirely in clear oil. Clutches sealed in this way have operated at speeds from 120 to 1440 rpm, and at slips varying from zero to 200 per cent, for 30 days with no visible evidence of iron particle leakage (Fig. 1).

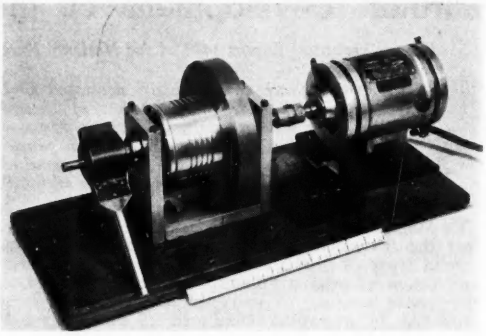


Fig. 4. **High-speed magnetic fluid clutch.**

When thick grease lubricants are used, the sealing problem is somewhat simpler since the iron-grease mixture tends to stay in the working gap. Air intake, however, causes trouble, and hermetic seals are still required to make the clutch independent of ambient conditions. This is also true of clutches employing dry lubricants.

Settling of the Iron Powder

When the magnetic fluid clutch was first developed, it was anticipated that the settling of the iron powder during stand-still periods might cause difficulties. However, as the clutch stirs itself very effectively, this has not proved to be a major source of trouble. In some applications, where the clutch serves as an overload device, or where permanent magnets are used and the clutch is never demagnetised, settling presents no problem at all.

If settling is undesirable for special reasons, it can be minimised in several ways. For example, some residual magnetism may be left in the iron during periods of disuse to keep the particles in their normal position. This means, of course, that more elaborate electrical controls are required where it is necessary to have the clutch release completely. Thixotropic greases, which resist flow but are easily stirred, can be employed to minimise settling, or the gaps can be so designed that the iron powder is kept in essentially the right place by mechanical locks on each side of the gap. The use of wetting agents has been found to make the magnetic fluid easily miscible and to give it thixotropic properties. When graphite is used as the lubricant, centrifugal force produces a hard-packed iron-graphite mass which stays in place when the clutch is not operating.

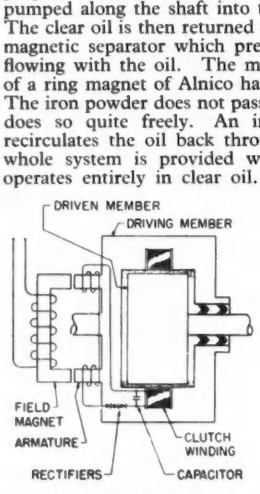


Fig. 5. **Self-excited magnetic fluid clutch.**

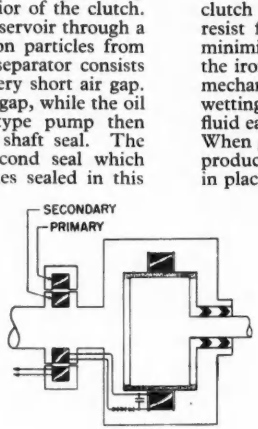


Fig. 6. **Transformer-excited magnetic fluid clutch.**

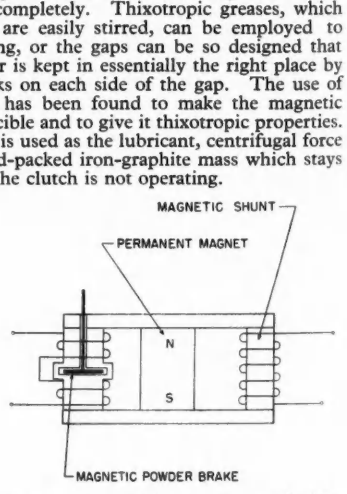


Fig. 7. **Two-way shunt system used with a magnetic-powder brake.**

Centrifuging Problem

In some of the early magnetic fluid clutches, difficulties were caused by the pressures produced on the iron particles by centrifugal force. In fact, some clutches of this type would not release at high speed. In disk-type clutches the effect was particularly noticeable since the centrifugal pressures on the iron particles in these clutches may be equal to or greater than those developed by magnetic attraction.

In most of the clutches now being built, the driving and driven parts are two coaxial cylinders (Fig. 2). These clutches avoid difficulties due to centrifugal force by using only enough iron powder to fill or not quite fill the working gap between the cylinders. Additional space can be filled with oil, or not, as desired. Then, at moderately high speeds, the centrifugal forces on the particles are overcome by the magnetic forces. This keeps the particles in the gap for operation of the clutch.

When still higher speeds are required, however, the simple cylindrical clutch is not entirely satisfactory since the magnetic forces are not then great enough to balance the centrifugal forces. The Bureau therefore developed a clutch of special design to operate at speeds of 10,000 rpm or more. In this clutch, the outside case is made of non-magnetic material, and the working gap is concentrated in a small annular volume just inside the outer case and enclosing the two circular pole pieces (Figs. 3 and 4). In this way the magnetic forces are made to act against the centrifugal forces and to overcome them for high speeds. Another advantage of this type of clutch is that when the magnetic field is removed, the particles separate from either or both of the magnetic surfaces and the clutch releases completely. If no excess lubricant is used, there is no drag.

Electrical Problems

The electromagnetic field for operation of the clutch can be energised by means of an external source of electrical power connected to the clutch by slip rings, or a stationary magnet may be used to transmit the flux to the working members through air gaps. Another possibility is to build a generator into the clutch itself. The alternating current thus produced can be rectified by suitable means and fed through the clutch coils. One advantage of this technique is that permanent-magnet exitation can be used for the generator. Also, since the clutch requires only a very small amount of electrical energy, the generator can be simple and of inexpensive design. The magnetic field can be varied either by changing the electromagnetic field of the generator or by moving the permanent magnet towards or away from the poles (Fig. 5).

Use of a transformer provides still another method of exciting the clutch. A stationary primary structure induces alternating current into a secondary which is mounted on the clutch and separated from the primary by two small air gaps. This alternating current is either used directly in the clutch windings or converted to direct current by suitable rectifiers (Fig. 6).

For many applications it is desirable that the clutch be kept locked most of the time and be released only when current is applied. This is particularly necessary in hoists, for example, in order that power failure may not cause the release of a brake or a clutch. One of the best ways of doing this employs a permanent magnet so arranged that the application of current shunts the flux away from the clutch into a by-pass, thus releasing the clutch without demagnetizing the permanent magnet (Fig. 7). Various mechanical methods for controlling the flux from permanent magnets either by moving the magnet itself or by moving appropriate shunts have been suggested. Some of these employ the principle of the magnetic chuck used in grinders and lathes for holding work-pieces. In some applications where demagnetisation is permissible, the clutch is controlled by magnetising and demagnetising " permanent " magnets.

Speed of Response

It has been found that the response time of the clutch —that is, the time required to energise and de-energise it—depends almost entirely on the response rate of the magnetic circuit rather than on the action of the iron particles. The speed of response of the magnetic circuit, in turn, is a function of the inductance of the winding and of the voltage of the source that supplies the current. As in all magnetic devices, laminating the iron structure aids in reducing eddy currents which tend to slow up the rise and decay of magnetic fields.

Magnetic-particle friction could also be used for the transmission of power between cylinders, cones, and other structures which are not necessarily coaxial. In such variations of the old cone-and-disk type of variable-speed friction device, the friction between solid surfaces is replaced by friction between solid members and a magnetic powder (Fig. 8).

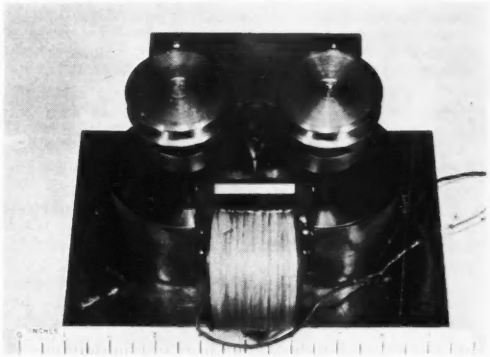


Fig. 8. **A magnetic transmission which utilises the principle of the NBS magnetic fluid clutch.**

It has also been suggested that magnetic fluid clutches could be substituted for the one-way clutches used in oscillating variable-speed transmissions. In these mechanisms, a rotary motion is first converted to an

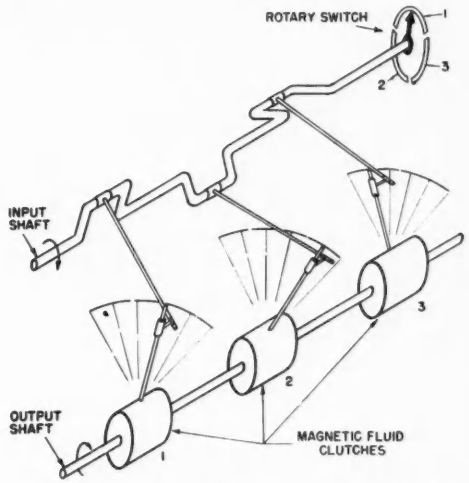


Fig. 9. **An oscillating variable-speed transmission, in which rotation is first converted to an oscillatory motion and then transformed, by means of clutches, back to rotary motion.**

oscillatory motion, which is then transformed, by means of one-way clutches, back to a rotary motion at a lower speed. Speed is varied by changing the stroke of the oscillatory motion. By use of magnetic fluid clutches with properly excited magnetic fields, a considerably smoother and perhaps more efficient transmission of this type could be achieved than has previously been possible (Fig. 9).

GERMANY

Measurement of Pressure by means of Metallic Test-Pieces

By E. FISCHER. (From *VDI-Zeitschrift*, Vol. 93, No. 2, January 11, 1951, pp. 37-40, 13 illustrations.)

Loads can be measured by means of metallic test-pieces, preferably made of electrolytic copper. The test-piece is subjected to the load to be measured, the magnitude of which is later indicated by a break in the stress-strain curve. The procedure is suitable for both static and impact tests, and has the advantage of cheapness.

EXPERIMENTS on load measurement by the use of compressible materials* have recently been extended to the employment of metals as test materials. The choice of material is, however, restricted by the following conditions :

1. Only such metals can be used as are capable of exactly indicating the magnitude of a load after this has been applied.
2. Non-plastic or only moderately plastic metals, such as iron, steel, brass, bronze, etc., cannot be employed.
3. The melting point of the metal must not be below a certain temperature. Low melting-point metals have a tendency towards stress-relaxation. In this group are lead, tin, zinc, cadmium, and bismuth.
4. The use of alloys should be avoided, as their composition may be difficult to reproduce ; also, they are often less plastic than their constituents.
5. Expensive, rare, and easily corroding metals can also be disregarded.

Experiments showed that copper and aluminium are the most suitable test materials. By a suitable choice of load and dimensions, the change of direction in the stress-strain curve can reach a value of almost 90 degrees, and the continuation of the curve coincides with the curve of a non-preloaded specimen. (Fig. 1.)

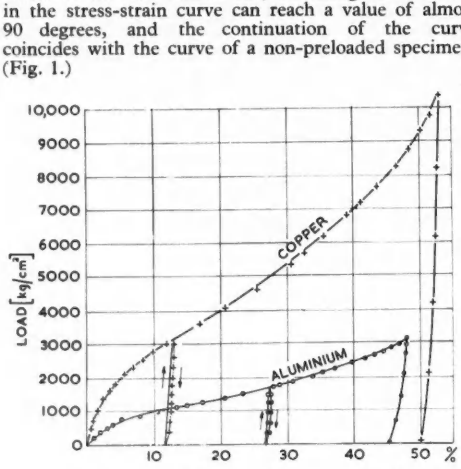


Fig. 1. **Stress-strain diagram of copper and aluminium.**

Copper has the further advantage over aluminium that re-crystallisation sets in at a higher temperature, and aluminium also shows a time-dependence on strain. For this reason, the investigations were carried out on commercial electrolytic copper.

*E. FISCHER, *VDI-Zeitschr.*, Vol. 92 (1950), pp. 167-68.

With respect to duration of load, three types of loading were employed :

1. *Short-time load.* Application of load for periods of the order of one minute.
2. *Long-time load.* Application of constant load for ¼ hour to several hours. Any time-dependent effects will have fully developed within this time.
3. *Impact load.* Load application for a fraction of a second.

SHORT-TIME LOAD

Compression tests were performed on test specimens measuring 10 × 10 × 4 mm. The stress-strain diagram is shown in Fig. 2, where the mean values are given by the full line, and the limits of spread of experimental values by the dotted lines. An upper limit to obtainable pressures is set by the deformation of the surfaces through which the load is applied.

If the application of pressure is interrupted at a particular value, the stress-strain diagram will show a practically perpendicular drop (Fig. 1). If load is again applied, the new curve will retrace the descending portion very closely and, on reaching the previous maximum load, will, after a sharp break, continue the interrupted yield-curve. The value of the preload can be estimated from the position of the break with an accuracy of a fraction of a per cent.

The initial, steep part of the curve is not suitable for accurate measurements ; the useful region lies between 2000 and 10000 kg/cm².

LONG-TIME LOAD

If the pressure is maintained for a longer time, the thickness of the specimen will slowly continue to decrease. The rate of decrease gradually becomes less,

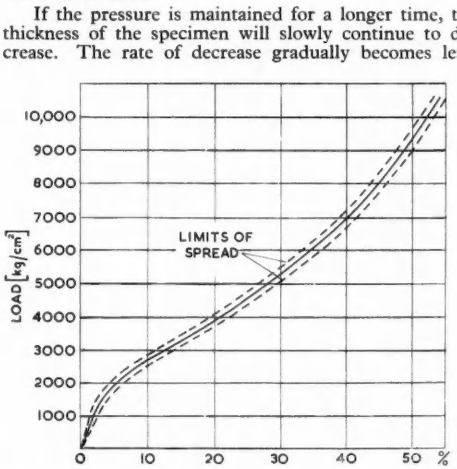


Fig. 2. **Stress-strain diagram of electrolytic copper, short-time loading.**

and after one hour it is negligibly small from the point of view of the test. The stress diagram obtained under these conditions is very similar to Fig. 2, but lies somewhat lower (see Fig. 5).

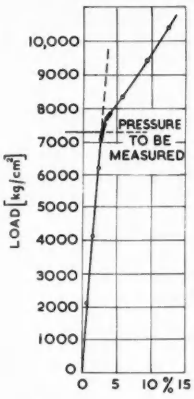


Fig. 3. **Influence of duration of load on break in analytical curve.**

If the load application is interrupted in this case, and a second application is made, this latter process would be carried out at the short-time rate. This second curve would, therefore, after the preload has been reached, form a continuation of the short-time curve. Thus, a sharp break cannot be expected in this case, but rather a rounding off in the preload region, (Fig. 3).

The steeply ascending part begins to change direction at the point of the previous maximum load, and then gradually merges into the short-time load curve. With accurate work, the error in the value of the load can be restricted to 1 to 3 per cent.

Impact Load

Fig. 4 shows the stress-strain diagram for impact loads of about 0·1 sec duration. Values below 2000 kg/cm² have a wide scatter, but their significance is small in any case. When the loading process was interrupted in this series of tests, and a preload investigation made, as above, the load value indicated by the break in the stress-strain diagram was consistently lower than the actual value. The indicated values have also been plotted, and by means of such an auxiliary curve a relatively accurate load measurement is possible in this case also.

Comparison of the Three Loading Types

Fig. 5 contains the mean values for short-time, long-time and impact loads. The difference between these curves is due to the different load-durations. The dotted line gives the indicated value of load after impact loading (see Fig. 4). It may be assumed that for impacts of a duration even shorter than 0·1 second, this curve would approach more closely the long-time curve. Pending further experiments, it is therefore suggested

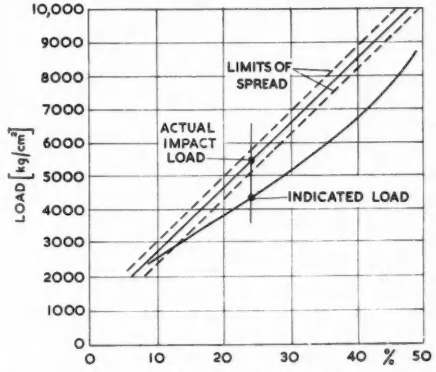


Fig. 4. **Stress-strain diagram of electrolytic copper, impact loading.**

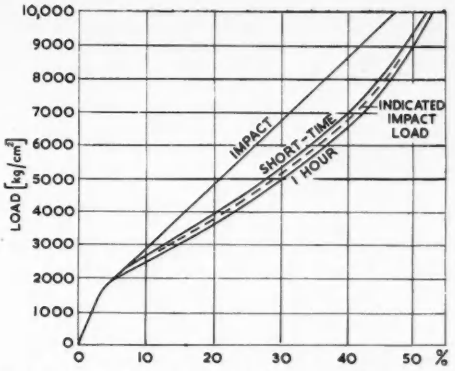


Fig. 5. **Mean values of stress-strain curves for load applications of various durations.**

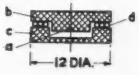
that the latter may be used for measurements of impact load.

The experiments showed further that copper retains its state of strain for some time, so that the load evaluation need not follow the original application of load immediately, but may be performed at a convenient time.

Measurement of Pressures below 2000 kg/cm²

The stress-strain curves so far discussed show a steep rise in the region below 2000 kg/cm², and are thus unsuitable for accurate measurements. However, by using a test-piece of different design (Fig. 6), which consists of a thin copper spiral held between two hard steel plates, 12 mm in dia., the strain-characteristic is remarkably altered, as shown by curve *a* in Fig. 7, in which the characteristic for the square test-piece is shown by curve *b* for comparison. The difference is due to the high specific pressures on the wire as compared with the plate. Although the experimental spread of results is in this case greater, it can be reduced by ensuring that the windings of the spiral do not touch during the application of the load.

Fig. 6. **Pressure gauge for loads up to 5 tons.**
a spigot, *b* and *c* steel plates, *d* copper wire.



The " pressure gauge " is only 4 mm thick, and can be used for loads up to 5000 kg. In practice, the pressure will not be completely perpendicular to the surfaces, so

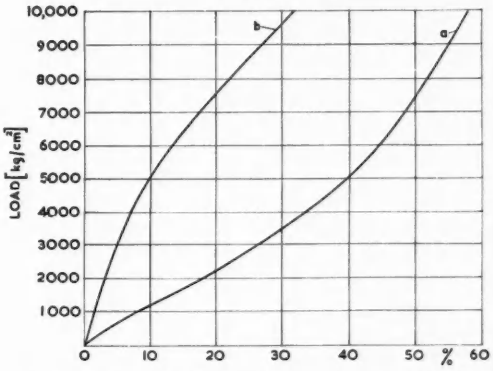


Fig. 7. **Stress-strain diagram for pressure gauge according to Fig. 6.**

that the plates *b* and *c* will usually include a small angle. In applying the load to be analysed, it is advisable, therefore, to use some arrangement by means of which the faces can assume their previous position (as guided by the compressed copper spiral between them).

While the application of the procedure described is necessarily limited to laboratory and development applications, it can give useful service in this field.

FRANCE

Electrical Analogy Determination of Torsional Vibration Frequencies of Shaft Systems

By M. BALLET. (From *Revue Générale de Mécanique*, Vol. 34, No. 24, December, 1950, pp. 429-434, 13 illustrations.)

The following article gives four different electro-mechanical analogies for torsionally vibrating systems and describes the equipment used. Equivalent circuits for geared systems are given as well as the results of a study of various alterations to an engine-and-airscrew system.

EQUIVALENT electrical circuits are being increasingly used for the determination of the natural frequencies and amplitudes of mechanical systems. In each case, the analogy is based on the fact that the two equivalent systems are governed by similar differential equations.

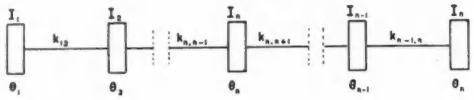


Fig. 1.

Thus, in a torsionally vibrating system of the type shown in Fig. 1, the motion of the *n*th moment of inertia I_n is determined by

$$I_n \ddot{\theta}_n + k_{n,n-1}(\theta_n - \theta_{n-1}) + k_{n,n+1}(\theta_n - \theta_{n+1}) = 0 \quad (1)$$

where θ_n = vibration amplitude of I_n, k = shaft stiffness, and $\cdot = d/dt$. There are various electrical circuits which are governed by equations of this type. For instance, the circuit of Fig. 2 is determined by

$$L_n \ddot{q}_n + \frac{1}{C_{n,n-1}}(q_n - q_{n-1}) + \frac{1}{C_{n,n+1}}(q_n - q_{n+1}) = 0 \quad .. \quad (2)$$

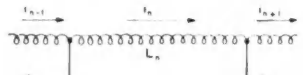


Fig. 2

and the circuit of Fig. 3 by

$$C_n \ddot{\Phi}_n + \frac{1}{L_{n,n-1}}(\Phi_n - \Phi_{n-1}) + \frac{1}{L_{n,n+1}}(\Phi_n - \Phi_{n+1}) = 0 \quad .. \quad (3)$$

In these equations, L = inductance, q = quantity of electricity, C = capacitance, $\Phi = \int V dt$ = flux, V = voltage.

The corresponding elements of the electrical and mechanical systems are, therefore, as follows :—

Mechanical	Electrical I	Electrical II
θ	q	$\Phi = \int V dt$
$\dot{\theta}$	$\dot{q} = i$	$\dot{\Phi} = V$
$\ddot{\theta}$	$\dot{q} = di/dt$	$\ddot{\Phi} = dV/dt$
I	L	C
$I\ddot{\theta} = T$	$L\ddot{q} = V$	$C\ddot{\Phi} = i$
k	$1/C$	$1/L$

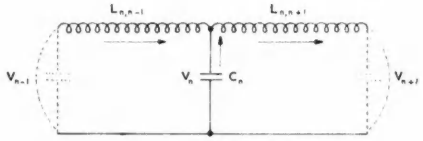


Fig. 3

The electrical analogy I is more convenient for determining the shaft torques $k\theta$, while analogy II is more suitable for determining the vibration amplitudes of the individual masses. Typical applications of these analogies to geared systems are given in Figs. 4 and 5.

In analogy I, a gear wheel driving *n* follower wheels corresponds to a " mesh " comprising 1 inductance and $n + 1$ capacitances. In analogy II, it corresponds to a " nodal point " to which 1 capacitance and $n + 1$ inductances are connected.

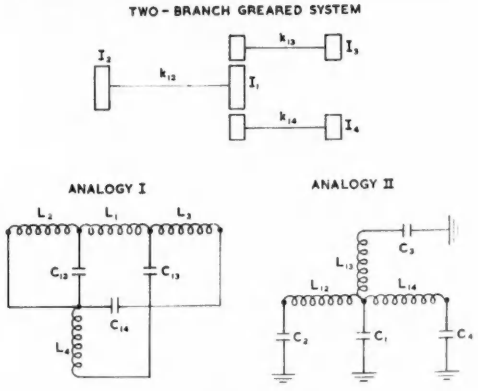


Fig. 4

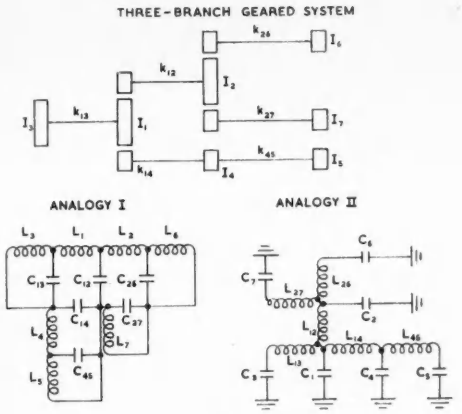


Fig. 5

TEST METHODS AND EQUIPMENT USED TO REPRESENT THE MECHANICAL SYSTEM

The equipment consists of a number of four-terminal cells comprising an adjustable capacitance and an adjustable inductance, connected as shown in Fig. 6. The inductance can be varied from 0 to 109 millihenries in steps of 1 millihenry. The capacitance is variable over the range 1-121 milli-microfarads. The $L\omega/R$ factor of the inductances is greater than 35.

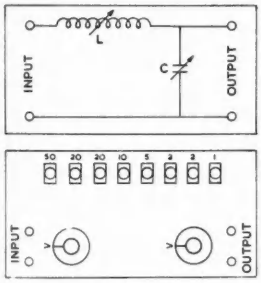


Fig. 6

The input is supplied by a beat-frequency oscillator covering the entire range from 20-20,000 cps with an accuracy of 1 per cent. A cathode-ray oscillograph is used for monitoring purposes, and accurate readings are taken by means of a valve voltmeter.

By changing over the connections, it is easy to pass from analogy I to analogy II, as illustrated in Fig. 7.

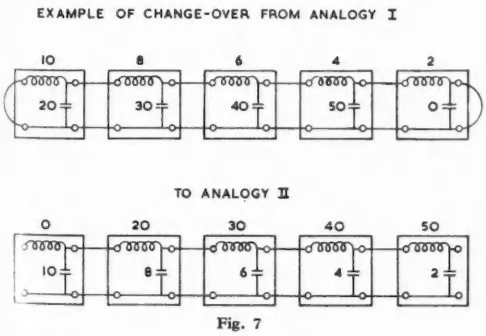


Fig. 7

The electrical network is connected to the supply system as shown in Fig. 8 (case of a straight shaft system with gear units, using analogy I). The oscillator is connected to earth on one side and to one of the inductance terminals on the other, via a low capacity condenser of the order of 1 mμF, which has to be taken into account since it is added to the capacitance at the oscillator terminal. Resonant amplitudes are first indicated on the oscillograph screen and then read off the valve voltmeter.

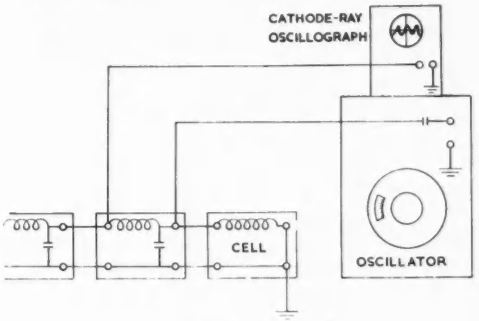


Fig. 8

In taking amplitude measurements, it is necessary to know whether the vibrations are in phase or in antiphase with respect to the input. For this purpose, the circuit of Fig. 9 is used. This circuit adds a constant potential difference, in phase with the oscillator input, between the output terminal of the voltmeter and the earth. This potential difference is adjustable by means of the two resistance boxes R_1 and R_2 and its value is chosen so that it will be small in comparison with the voltages to be measured.

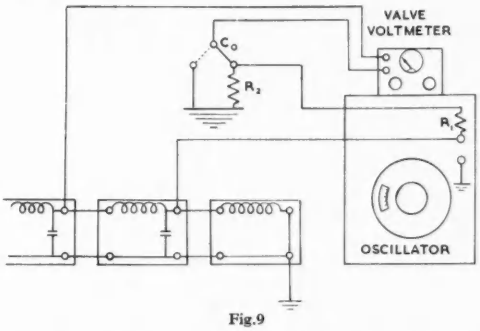


Fig.9

The change-over switch C_o is then connected either directly to earth, or to earth via the resistance R_2. If the voltmeter reading is greater in the second case, the measured voltage is in phase with the input ; if not, it is in antiphase. Measurements are taken in this manner at the terminals between each inductance of the network.

The relationship between the natural frequencies of the mechanical and electrical systems is easily established. Since L is in millihenries and C in milli-microfarads, the radian frequency of the electrical system is given by $\Omega^2 = 10^{12} \times 1/(LC)$. For a one-mass system, with a mass moment of inertia I and an equivalent length l, the natural frequency is determined by $\omega^2 = K/(I\,l)$, where K = constant equal to the product of the modulus of rigidity and the polar moment of inertia of the shaft section. Putting either $L = I$ and $C = l$ (analogy I), or $L = l$ and $C = I$ (analogy II), we then obtain

$$\omega = \Omega 10^{-6}\sqrt{K}.$$

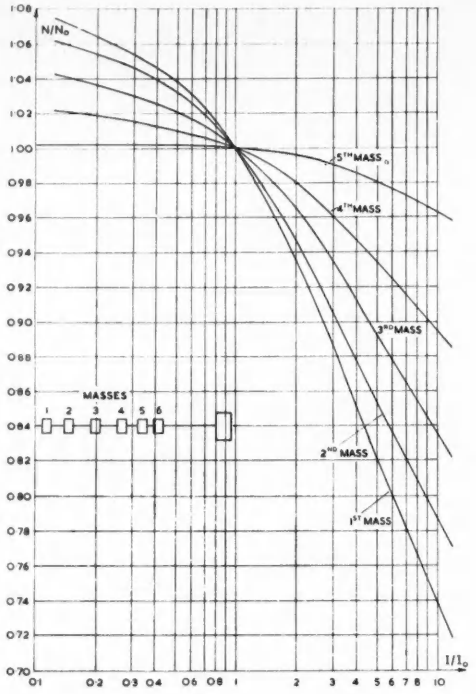


Fig. 10

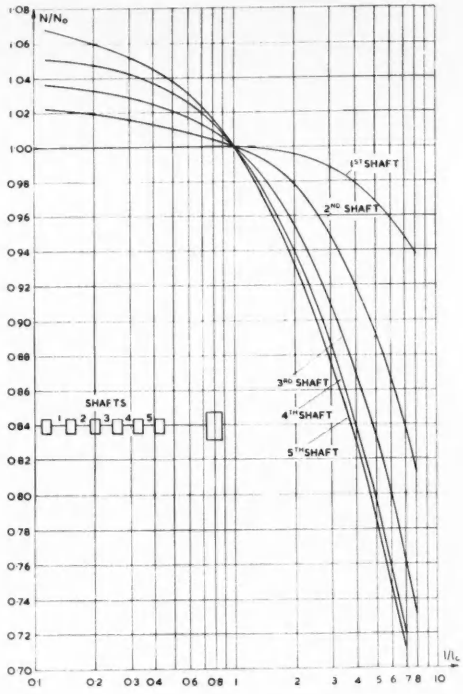


Fig. 11

The measurements give an accuracy of 1-2 per cent for the natural frequency and 4-5 per cent for the vibration amplitudes, and can be carried out in 30 minutes to 1 hour depending on the complexity of the system and the number of modes of vibration investigated. Increased accuracy is obtainable by checking the frequencies by means of a frequency-meter. The amplitude measurements are less accurate because they are dependent on the frequency.

A major advantage of the electrical analogy methods is that they permit a rapid determination to be made of the effects of an alteration to a given system.

As an example, the following results are given of the study of a six-cylinder in-line aircraft engine system coupled to an airscrew. The ratio of the inertia of the airscrew to the inertia per cylinder was $\gamma = 3$, and the ratio of the equivalent length of the airscrew shaft to the equivalent length of one crankthrow was $\rho = 4$. Each of the six inertias of the engine was successively modified according to the ratios $I/I_0 = 0{\cdot}125$, $0{\cdot}25$, $0{\cdot}5$, $0{\cdot}75$, $1{\cdot}5$, 2, 3, 4, 5, 6, 7, 10 and 12. Similarly, the equivalent length of each crankthrow was modified according to the ratios $l/l_0 = 0{\cdot}113$, $0{\cdot}33$, $0{\cdot}5$, $0{\cdot}75$, $1{\cdot}5$, 2, 3, 4, 5, 6, 7 and 8, where the subscripts 0 denote the original values.

The frequency ratio N/N_0 was then plotted, first as a function of I/I_0, and then as a function of l/l_0, with the abscissae based on a logarithmic scale. The results, shown in Figs. 10 and 11, respectively, are in agreement with the theoretical curves calculated by LEHR.

OTHER ANALOGIES

Further electro-mechanical analogies have been developed by G. CAHEN, in investigating the bending vibrations of beams, and are also applicable to torsional vibrations. The analogies III and IV give the following corresponding elements :—

Mechanical	Electrical III	Electrical IV
θ	q	Φ
$\dot{\theta}$	$\dot{q} = i$	$\dot{\Phi} = V$
T	V	i
I	$1/C$	$1/L$
k	L	C

CONSTANT INPUT-FREQUENCY METHOD

Measurements can also be carried out by using a constant-frequency input, for instance, 480 cps, and altering the values of the electrical elements of the network. However, this method requires the use of condensers and inductances with values that can be varied in the ratio of 1:1000 at least. Although this method, suggested by C. CONCORDIA, is probably more accurate, it is less rapid and less obvious than the method using an oscillograph and a variable-frequency oscillator.

BIBLIOGRAPHY.

LOEB, J. and CAHEN, G. Electrical networks and mechanical transmissions. Assocn. Technique Maritime & Aéron., Session of 1948.

LEHR. On a method permitting simpler calculation of natural frequencies of torsional systems and giving an assessment of the effects of alterations to the vibrating system. 6th International Congress of Applied Mechanics, Paris, 1946.

RIGBY, C. P. Longitudinal vibration of marine propeller shafting. Engineering, April, 1948.

CAHEN, G. New electro-mechanical analogies. Preprint of Soc. Française des Electriciens, not yet published.

CONCORDIA, C. Network analyser determination of torsional oscillations of ship drives. Trans. Soc. Naval Architects and Marine Engineers, Vol. 51, 1943.

New Materials, Processes and Equipment

AIR-OPERATED DIE CASTING MACHINE

The A.B.C. Die Casting Machine Company, Chicago 28, has announced an air-operated zinc die-casting machine with completely automatic cycling and adjustable timing dwell on the opening and closing of the toggle and injection of the molten metal. The machine will produce castings up to 1 lb in capacity

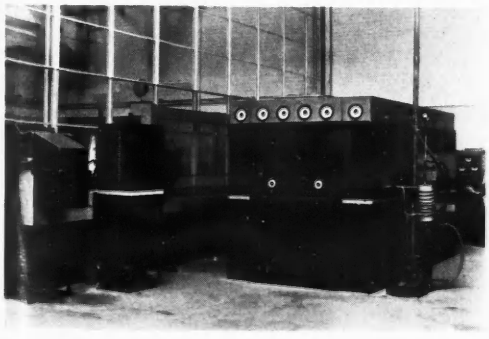
utilising die blocks from 1½ in. thickness by 8 × 10 in. with an allowable increase in die thickness up to 3 in. for each half. The machine is equipped with a 200-lb pot and is capable of a free cycling speed beyond 1000 shots per hour. The machine was primarily designed for economical single-cavity dies in view of its speed in production.

HIGH-FREQUENCY INDUCTION GENERATOR

This equipment, manufactured by Philips Electrical Limited, has recently been installed at De Havilland Propellers Ltd., Hatfield, for hardening purposes, and represents the most powerful and up-to-date valve driven high-frequency generator in Europe.

It is designed for operation on a mains supply voltage of 380-440 V, 3-phase, 50 cycles, and requires a maximum mains power input of 280 kVA. At 150 kW output the power factor is 0·9 and the nominal operation frequency 275 kcps.

The built-in variable coupling transformer for " on load " control of output power is designed to allow for a choice of automatic or manual operation. Tapped H.T. secondary voltages are available. The valve complement consists of one oscillator valve, one grid bias valve, and six rectifier valves. The filament voltage of the oscillator valve is maintained constant by an automatic, motor-driven regulator. A wide choice of automatic operating-time ranges is effected by the fitting of two synchronous motor timers. All circuits are fully fused and fitted with adequate safety precautions; neon lamps indicate the satisfactory operation of interlock devices.



NEW RESISTANCE SPOT WELDER

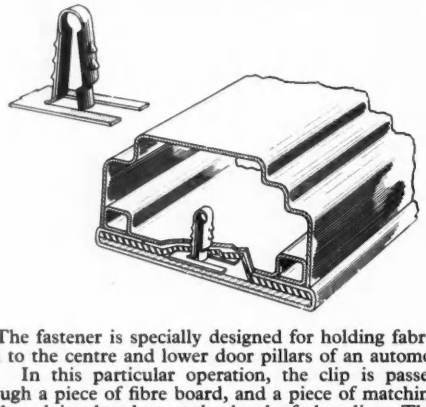
A new resistance welder for spot-welding aluminium, magnesium, stainless steel, Inconel, Monel, brass, mild steel and other alloys has been developed by Sciaky Bros., Chicago. This welder is unique in that the same machine can be quickly and easily adjusted, by change of control settings, to welding any one of the above-mentioned metals, and will handle various thicknesses of each. Previously, resistance spot welders have been much more limited in range of material and thickness that any one machine could handle. This machine will weld heavier thicknesses of aluminium, so that it is applicable to welding various aircraft components including primary structural members. No costly changes in the machine are necessary to change from one thickness of a material to another.

The welding current is controlled by a continuous wave, which may be altered to suit the thinnest or thickest metals within the welder's range. An adjustable current decay control permits precise control of the cooling rate of weld nuggets, so that the metallurgical structure is sound and internal stresses and cracks can be avoided. When welding two or more pieces of substantially different gauge thickness, uni-directional current is used to ensure proper welding. Control of current direction is readily accomplished by operating a simple toggle switch. For welding of heavy gauges of ferrous alloys, pulsation controls are provided. The heating and cooling time as well as the total number of

successive alternating pulses can be controlled. This welder also includes an adjustable pressure regulator for controlling the time at which the forging pressure is applied in relation to the peak of welding current. This assures an optimum weld quality regardless of gauge thickness.

SPEED CLIP

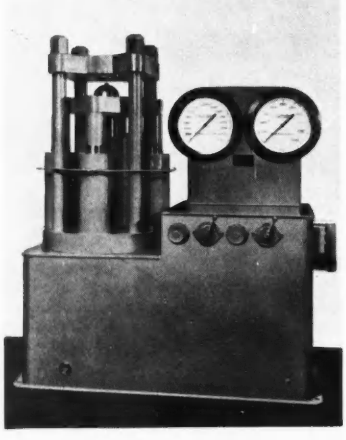
Installation or interior trim on automobiles is simplified by a specially designed speed clip announced by Tinnerman Products, Inc., of Cleveland, Ohio. The new clip is made of heat-treated spring steel, 0·02 in. thick. It consists of a head 31/32 in. long and $\frac{5}{8}$ in. wide, from which arises a spring bent into the shape of a dart. The dart-shaped portion of the clip contains barbs. Snapped through a hole in a flat piece of material, this portion of the clip contracts and expands, holding the material securely against the head.



The fastener is specially designed for holding fabric trim to the centre and lower door pillars of an automobile. In this particular operation, the clip is passed through a piece of fibre board, and a piece of matching cardboard is placed over the head of the clip. This sandwiches the head. Fabric is then stretched over both pieces of board and secured with an adhesive. This assembly is then simply and neatly snapped into holes provided in the door pillar.

DUCTILITY-TESTING MACHINE

A new ductility-testing machine providing a total capacity of a quarter of a million pounds pressure and incorporating a unique 5-in. diameter penetrator has been made by Steel City Testing Machines, Inc., Detroit, for the Kaiser Steel Corporation. Purpose of the unit is to detect surface and sub-surface imperfections in deep-drawing steel over a comparatively large area.

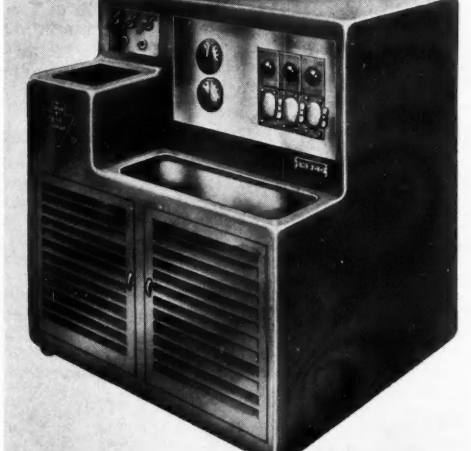


The hydraulically operated machine provides separate controls for clamping the sample and for regulating the penetrating pressure. Penetrating pressures can be applied up to 150,000 lb while clamping pressures are provided up to 100,000 lb. Equipped with a set of three dies for use with different gauges of metal, the machine will test material of up to $\frac{1}{4}$ in. thickness.

Although the conventional $\frac{7}{8}$-in. diameter penetrator used in most ductility-testing machines satisfactorily determines the ductility of steel, it was felt that cup testing over a larger area would afford a greater opportunity of detecting surface and sub-surface imperfections. A short $\frac{7}{8}$-in. diameter extension on top of the 5-in. diameter penetrator affords an opportunity for comparison with the $\frac{7}{8}$-in. standard method. To aid in the evaluation of results, the area involved in the test is inscribed with a 1-in. grid which can be correlated to the grid pattern of drawn parts.

HOT-COLD TEST STAND

This unit, made by George L. Nankervis Company, Detroit, will produce any temperature between — 77° F and + 230° F. Producers of aircraft parts are frequently required to determine operating characteristics of sub-assemblies at temperatures equivalent to those encountered in actual flight conditions. These temperatures, which range from a maximum of 230° F to a minimum of minus 70° F, are now available in the hot-cold test stand.



Designed for testing small aircraft parts, the test stand has a deep well which can accommodate parts measuring up to 6 × 6 × 8 in. The item to be tested is simply placed in the deep well and the thermal selector set at the desired temperature. The deep well is then chilled or heated to the selected temperature.

To accommodate testing of small parts which are mounted on larger assemblies and cannot be placed in the deep well, the thermal fluid can be circulated in a closed system a short distance from the test stand in insulated lines.

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

ELECTRICITY AND MAGNETISM

Magnetostriction of Iron-Aluminium Alloys

By K. HONDA, H. MASUMOTO, Y. SHIRAKAWA and T. KOBAYASHI. (From *Science Reports of the Research Institutes*, Tohoku University, *Japan*, Series A, Vol. 1, No. 4, 1949, pp. 341-347, 4 illustrations.)

THE magnetostriction of 17 kinds of Fe-Al alloys containing up to 16·56 per cent Al was measured by a new apparatus in various fields of less than 1,200 Oersted. At the same time, the intensity of magnetisation was measured and the following results were obtained :

The measured values for iron are the same as those obtained by other investigators. An addition of aluminium to iron generally results in a gradual increase of the positive maximum value of magnetostriction, but in a decrease of its negative value. In alloys containing more than 5·9 per cent Al, magnetostriction is always positive. Alloys with more than 8·8 per cent Al have no maximum magnetostriction, the values increasing with the magnetic field or the intensity of magnetisation. At a constant magnetic field of 1,100 Oersted, magnetostriction of alloys containing less than 5·3 per cent Al is negative, but it is positive for greater percentages, while the intensity of magnetisation gradually decreases with increasing Al-content. In the range of an aluminium content of 11·5 to 13·2 per cent, magnetostriction is very high. Alloys containing 13·14 per cent Al are excellent magnetostriction materials (40×10^{-6}) in a magnetic field of 1,200 Oersted. They are suitable for use in ultrasonic magnetostriction transducers.

MATERIALS TESTING

The Fatigue Strength of Welded 18-8 Steel at High Temperature

By I. WEIBULL and P. DAVIDSON. (From *Jernkontorets Annaler, Sweden*, Vol. 134, No. 12, 1950, pp. 559-571, 17 illustrations.)

THE fatigue strength of welded 18-8 steel sheet at a temperature of 650° C was investigated. Four different steel qualities were tested, of which two were stabilised with titanium, one was stabilised with niobium, and one (with a very low carbon content) was unstabilised. The best results were obtained with a titanium-alloyed steel, which was free from grain boundary carbide and which had a very low content of δ-ferrite in the weld and junction zone. There is every reason to suppose that niobium-alloyed steel would give at least as good results under similar conditions. The δ-ferrite may be largely removed either by raising the nickel content or by heat treatment. If the carbon content is higher than 0·02-0·03 it is necessary to add niobium or titanium in order to avoid grain boundary carbides.

How Can Hardness Values be used in Metal Design

By J. B. CAMPBELL. (From *Materials and Methods, U.S.A.*, Vol. 32, No. 6, December, 1950, pp. 43-47, 1 illustration.)

ALTHOUGH hardness values can frequently be used to predict various service and fabrication characteristics, they must be used with an understanding of their limitations. The purpose of any set of mechanical properties is to enable the engineer or designer to (1) predict the behaviour of the material during fabrication, (2) predict the behaviour of structures fabricated from the material under actual service conditions, and (3) compare the material with others for both fabrication and service.

Hardness values alone cannot be used directly to achieve either of the first two objectives. Fortunately, however, they can be related to other more useful properties. Of particular importance is the relationship between hardness and tensile and yield strengths, which appears to be especially valid for ferrous metals. These are practical quantities which can be used directly in design.

Attempts have also been made to link hardness values with qualities such as wear resistance, machinability, and formability. These attempts have been only partly successful, since each of those properties also depends on a number of other factors not related to the hardness of the material.

Failure of materials and parts to behave in a manner predicted on the basis of hardness values has sometimes led engineers to describe the hardness test as " meaningless." The trouble is that the ordinary hardness value has too often been sold to engineers as a kind of patent medicine to be swallowed upon any pretext. This article attempts to explain simply and clearly the practical meaning of hardness values, and to show to what extent they can be used in metal selection and design.

PHOTOELASTICITY

Three-Dimensional Photoelasticity

By A. J. DURELLI and R. L. LAKE. (From *Machine Design, U.S.A.*, Vol. 22, No. 12, December, 1950, pp. 122-125, 9 illustrations.)

CREEP in plastics is being utilised in a new method of studying distribution of stresses. The conventional method of " freezing " the stresses has several limitations, the two most important being the need of an oven with precise temperature controls and the large permanent change of shape of the model during heating. The latter occurs because the moduli of elasticity of the plastics used decrease at high temperatures much faster than their optical sensitivities increase.

Freedom from mechanical and optical creep has long been one of the specifications of a good photoelastic material. Research on the creep nature of some photoelastic materials shows, however, that creep when properly used may be an advantage instead of a shortcoming.

The material studied was Catalin, a water-clear transparent phenol-formaldehyde casting resin. In Catalin, at room temperature and stresses up to about 1000 psi, optical creep is linearly proportional to stress.

This remarkable property can be used to advantage in two-dimensional photoelasticity, as a means of increasing the optical sensitivity of the material, as long as the correct fringe value is used to interpret the picture. When the material does not creep, the fringe value is constant. When the material creeps, the fringe value is a function of time.

The extent and permanence of the residual patterns suggested the possibility of substituting a period of loading at room temperature for the usual stress-freezing technique.

To check the validity of this method, a cylindrical

Photograph by courtesy of Howard & Bullough Ltd., Accrington.

Many of the machining difficulties usually presented by frail workpieces can be overcome by the use of Wimet tools. These motor bed plates, which are highly susceptible to vibration, embody flat surfaces milled in alignment requiring varying depths of cut up to $\frac{5}{16}$". Wimet cutters achieve a feed rate of 7.87" per min. on this delicate operation and usually are in production 7 days between relappings.

If you want to get the best out of carbide tooling ask for genuine Wimet and see that you get it—made only by Wickmans of Coventry.

Publications dealing with all aspects of carbide tooling are available. Write to the Wickman Technical Publications Department mentioning your interest.

A. C. WICKMAN LTD · COVENTRY · ENGLAND
LONDON · BRISTOL · BIRMINGHAM · MANCHESTER
LEEDS · GLASGOW · NEWCASTLE · BELFAST

Wimet

90 ST

shaft with a deep circumferential notch of hyperbolic form, subjected to pure tension, was chosen. The model was machined from a block of Catalin.

It is believed that the results obtained sufficiently demonstrate the validity of the creep-freezing method for those cases in which boundary conditions do not change during the course of the test. The technique is certainly not complete as yet. It is necessary to make a further study of calibration techniques, since the auto-calibration method may not be as practicable in many three-dimensional cases as it is in two dimensions.

PRODUCTION CONTROL

Dye Penetrant Quickly Reveals Surface Flaws

By A. GILBERT. (From *The Iron Age, U.S.A.*, Vol. 166, No. 20, November 16, 1950, pp. 91-92, 3 illustrations.)

MUCH research and testing resulted in the development of a new general purpose method of detecting surface cracks and discontinuities. It is a dye penetrant method of inspection which is completed in three easy steps. After cleaning the part, the first step is to apply the penetrant. The second step is to wash off the excess penetrant. The third step is to apply the developer. The theory behind the system is that some liquids will penetrate into minute cracks in metals. The special penetrant compound used is a liquid having exceedingly high capillarity and low surface tension, in which is dissolved a brilliant red dye. This liquid, having no viscosity, will penetrate into even the finest surface discontinuities and will remain there while the excess is removed from the surface.

It may be applied by spraying or dipping or by simply brushing on the surface. The excess dye is removed from the surface with a special cleaner by brushing, dipping or spraying. The developer is applied in the same manner. The developer consists of fine white solids suspended in a quick-drying liquid. It has two functions: (1) It provides a smooth white background to give good contrast for any indication; and (2) it draws the dye penetrant from the flaws. Indications of surface cracks and discontinuities show up as vivid red marks on a white surface. It is possible to estimate the size of the crack by the amount of bleeding or spread of the red dye. A crack is indicated by a red line or a series of connected red dots. Scattered disconnected dots indicate porosity.

THERMODYNAMICS

Measurement of Temperatures in High-Velocity Steam

By J. W. MURDOCK and E. F. FIOCK. (From *Transactions of the ASME, U.S.A.*, Vol. 72, No. 8, November, 1950, pp. 1155-1161, 10 illustrations.)

NORMAL progress towards more compact and more efficient power plants involves the handling and utilisation of the working medium at even higher temperatures, pressures, and velocities. Simultaneously with this trend towards more severe operating conditions there is a demand for increased accuracy in values of efficiency determined experimentally. This, in turn, requires a better knowledge of the state of the steam at various locations throughout the power plant, which can be obtained only with improved instruments and methods of measurement.

Studies have therefore been made of the performance, in moving air and steam, of various total-temperature-type wells suitable for use in steam at operating conditions. The instruments recommended for such applications, constructed so that the sensing element is surrounded by nearly stagnant steam, have temperature-recovery factors above 0·9, which do not change significantly with either the medium, its temperature, or its pressure. Although additional work remains to be done on reducing their sensitivity to flow direction and pattern, these wells, when installed in straight pipes through which steam is flowing at any velocity up to 725 fps, yield total enthalpies which are accurate to within 1 B.Th.U. per lb.

TRANSFORMERS

The Influence of Bending on Transformer-Core Laminations

By F. ASSMUS. (From *Frequenz, Germany*, Vol. 4, No. 8, August 1950, pp. 193-196, 2 illustrations.)

MU-METAL core laminations of high permeability are used extensively in telecommunications practice. In assembly, they are usually threaded into the coil by depressing the middle tongues of the laminations. It is found that this bending often results in permanent impairment of the magnetic qualities, and the object of these investigations was to establish a relation between permeability, thickness of laminations and degree of bending. Tests were carried out on standard parts of different thicknesses, and the conclusions drawn are that in many cases, the maximum thickness of laminations consistent with retention of high permeability is exceeded in practice. It is shown that very often the extra cost of using thinner laminations is more than counterbalanced by the improved permeability, in addition to reducing eddy-current losses.

The results in general show the sensitivity of high-permeability materials to small deformations, suggesting that this factor must be carefully considered where such materials are employed. While the tests were performed on German standard core stampings, the numerical results given could be applied to British practice.

CRITICAL SPEEDS IN CENTRIFUGAL PUMPS

(*Concluded from page* 80)

for large deflections, when the two shafts are touching each other. The above relation answers the requirement that $k = k_1$ for $y = 0$, and $k \simeq k_1 + k_2$ if y assumes a large value.

If the angular speed of the rotating shaft is ω, the equilibrium between the internal resistance and the centrifugal force leads to

$$y\left[k_1 + \frac{k_2 y^n}{a + y^n}\right] = m\,\omega^2 (e - y),$$

so that

$$\omega^2 = \frac{y}{e + y}\left[\frac{k_1}{m} + \frac{\dfrac{k_2}{m} y^n}{a + y^n}\right].$$

For the angular speeds ω concerned, the deflections y are large in comparison with the eccentricity e, and it can be stated approximately that

$$\omega^2 \simeq \frac{k_1}{m} + \frac{\dfrac{k_2}{m} y^n}{a + y^n}.$$

If the deflection y is large, but nevertheless small in comparison with a, the second term can be neglected, and

$$\omega \simeq \sqrt{\frac{k_1}{m}} = \omega_1.$$

If the deflection y is infinite,

$$\omega = \sqrt{\frac{k_1 + k_2}{m}} = \omega_2.$$

QUALITY · ACCURACY · SPEED · LONG LIFE

"SPEEDICUT" HIGH SPEED STEEL TWIST DRILLS

for all drilling operations.

A really complete range of sizes in 18% Tungsten High Speed Steel . . . .004in. to 4in. dia.

" SPEEDICUT C. T." drills of tough temper for construction work.

" SPEEDICUT " for general purpose drilling.

" SPEEDICUT SATIS " for maximum resistance to wear on high tensile and work-hardening alloys.

Your drilling problem may need drills of special design; we shall be pleased to make them and if need be arrange the visit of a Technical Representative.

Proved in reliability over two generations

Twist Drills - Reamers - Taps Milling Cutters - Lathe Tools - Chaser Dies - Segmental Saws - " Mitia " Carbide Cutting Tools " Mitia " Carbide Saws Saws for all purposes - Files and Rasps - Hacksaws " Hardometer " Hardness Testing Machine - Twist Drill Point Sharpening Machine - " Crypto Atlas " Bandsawing Machine " Mitia " Carbide Saw Sharpening Machine - And all other types of Engineers' Cutting Tools

FIRTH BROWN

TOOLS LTD. SHEFFIELD

NEWS OF THE MONTH

PERSONAL

Mr. Paul Adorian, M.I.E.E., M.Brit.I.R.E., A.F.R.Ae.S., President of the British Institution of Radio Engineers, has been appointed chairman of Redifon Ltd.

Dr. Archibald Morton Ballantyne, B.Sc.(Glas.), A.M.I.C.E., A.M.I.Struct.E., A.F.R.Ae.S., has been appointed secretary of the Royal Aeronautical Society, to succeed **Captain J. Laurence Pritchard.**

Mr. G. T. Bell, managing director of Stern & Bell Ltd., Birmingham, has been appointed managing director of Weldall & Assembly Ltd., Stourbridge.

Mr. P. J. C. Bovrill, general manager of the Chemical Works of Newton Chambers & Co. Ltd., and a director of the local board, has been appointed chairman of the Sheffield Centre of the Institute of Industrial Administration.

Captain (E.) Robert Cobb, O.B.E., R.N., has been promoted Rear-Admiral (E), on the staff of the Commander-in-Chief, Portsmouth.

Mr. Richard Crawford, M.I.Min.E., A.I.E.E., has joined the Mine Safety Appliances Co. Ltd., Queenslie Industrial Estate, New Edinburgh Road, Glasgow E.2., as general sales manager.

Mr. E. A. W. Hornett has been appointed secretary of the British Internal Combustion Engine Manufacturers' Association.

Mr. E. H. Hurlston, F.I.R.I., has been appointed technical manager of the Dunlop Rubber Co. Ltd., Manchester. **Mr. W. A. Clarke, B.Sc.,** has been appointed technical manager of the company at Speke, Liverpool.

Mr. E. H. Jefferson, quality controller of Hawker Aircraft Ltd., has been elected a director of the Company.

Mr. E. R. A. Milne, A.M.I.E.E., has been appointed branch manager for Scotland at the Glasgow office of Newman Industries Ltd., Yate, Bristol.

Mr. A. W. Morrison, B.Sc(Glas.), has been elected a director of Powell Duffryn Carbon Products Ltd.

Mr. A. Newing, A.M.I.E.E., managing director of Nevelin Electric Co. Ltd., has been appointed to the Board of Directors of Lancashire Dynamo Holdings Ltd., formerly Lancashire Dynamo and Crypto Ltd.

Major-General L. B. Nicholls, managing director of Cable and Wireless Ltd., has been elected chairman in succession of **Colonel Sir Stanley Angwin, K.B.E., D.S.O., M.C.,** who has joined the Commonwealth Telecommunications Board.

Mr. John Pascoe, deputy chairman and managing director of British Timken Ltd. and of Fischer Bearings Company Ltd., has been appointed chairman and managing director of both companies.

Mr. Edward H. Patterson has been appointed general manager of R. Y. Pickering & Co. Ltd., Wishaw, Scotland.

Mr. F. G. Penny, M.Inst.C.E., M.I.Mech.E., has been appointed managing director of International Combustion (Holdings) Ltd. and of International Combustion Ltd., in succession of Sir George Usher who resigned that position but remains a director of both companies.

Mr. Fred Rogers has been appointed manager of Brackley Colliery, Little Hulton, near Bolton.

Mr. L. Rotherham, M.Sc.(Lond.), F.Inst.P., F.I.M., has taken up appointment in the Ministry of Supply Atomic Energy (Production) Division, Risley, Warrington, Lancashire.

Mr. J. D. Sutcliffe has been appointed commercial director of Richard Sutcliffe Ltd., Horbury, Wakefield, Yorkshire.

Mr. G. H. Thornley, M.Sc.Tech., F.Inst.Pet., has been appointed technical manager of the Wakefield Group of companies.

Mr. D. N. Walker, M.I.Mech.E., has been appointed chief mechanical engineer at the London headquarters of the National Coal Board, Hobart House, Grosvenor Place, S.W.1.

Mr. B. H. C. Waters, has been appointed lecturer in Metallurgy at University College, Southampton.

INDUSTRIAL LEADERS TO HELP REARMAMENT PROGRAMME.

The Minister of Supply (Mr. George R. Strauss) has announced the following appointments:

Director General of Machine Tools: Mr. S. W. Rawson, managing director of John Brown Ltd. Mr. Rawson is a director also of Thomas Firth and John Brown, Firth Brown Tools Ltd., and more than 20 other subsidiary or associated companies engaged in engineering and shipbuilding.

Deputy Controller of Supplies (Aircraft) Production: Mr. W. C. Puckey, M.I.P.E., F.I.I.A., director and general works manager of Hoover Ltd.

Deputy Controller of Supplies (Munitions) Production: Mr. A. G. E. Briggs, A.M.I.Mech.E., assistant managing director of Tube Investments Ltd.

Chairman of Steel (Rearmament) Advisory Panel: Mr. E. W. Senior, commercial director of the Iron and Steel Federation, chairman of George Senior and Sons Ltd., and Padley and Venables Ltd., and a director of Ransom and Marles Bearings Ltd.

BUSINESS NOTES

Brookhirst Switchgear Ltd., Northgate Works, Chester, have opened a branch office at Lloyds Bank Chambers, 15, Sandhill, Newcastle-upon-Tyne 1. Mr. T. G. Evans has been appointed district manager and will be responsible for the company's interests in Northumberland and Durham.

The Gloster Aircraft Co. Ltd. has completed arrangements with the Fairey Aviation Ltd. for setting up a production line at the Avion Fairey Works, Gosselies, Belgium, in order to expedite deliveries of "Meteor VIII" jet aircraft to the Belgian Air Force.

McDonald Furnaces Ltd. announce that demand for plant designed and installed by the Company has necessitated the building of new workshops and offices. Work on the new site which is situated at Lawley Brook, Kingswinford, Staffs., has now commenced.

The administrative staff has been accommodated, for the time being, at the Company's offices at 22 Bilston Street, Wolverhampton, Telephone No. 21574, and further notice will be given when the new offices are occupied.

Metalock (Britain) Ltd., 638 Grand Buildings, Trafalgar Square, London, W.C.2, announce that following the establishment of offices in Amsterdam, Holland, Legnano, Italy, Drammen, Norway, Gothenburg, Sweden, Moshi, Tanganyika, Dublin and Glasgow, all of which are superintended by the London headquarters, Major E. C. Peckham, managing director, has now arranged for agencies in India, Pakistan, France, Portugal, the Iberian Peninsula, South Africa and Australia. The Metalock process of cold repair to iron castings enables carrying out repairs on the spot, without dismantling.

H. T. Watson Ltd., manufacturers of spraying equipment, have moved to larger premises offering greater facilities. Works and offices are now situated at Croft Street, Widnes, Lancashire, Telephone No. 2313.

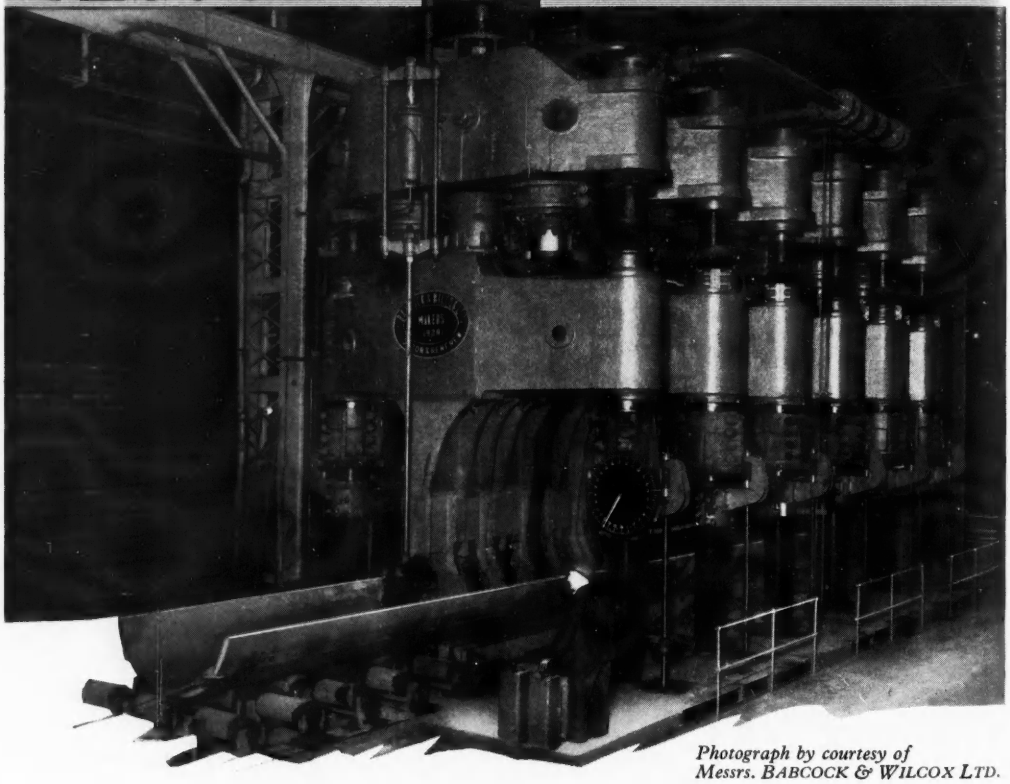
The Telegraph Construction and Maintenance Co. Ltd. (Telcon) and Mullard Electronic Products Ltd., announce the formation of a new company to be known as Telcon Telecommunications Ltd. The object is to promote and co-ordinate the development, manufacture and sale of Telcon cables and Mullard equipment associated with land line telecommunications. The registered office is at 22 Old Broad Street, London, E.C.2.

The first directors are Mr. J. N. Dean, B.Sc., A.R.I.C., Mr. J. Innes, C.B., B.Sc., M.I.E.E. and Mr. R. C. Mildner, M.Sc., M.I.E.E. representing Telcon, and Mr. J. P. Jeffcock, O.B.E., M.I.E.E., Mr. C. L. G. Fairfield, M.A., A.M.I.E.E., A.M.I.Mech.E., Barrister at Law, and Dr. C. F. Bareford, M.Sc., Ph.D., A.M.I.E.E. representing Mullard.

Mannex (London) Ltd. have re-organized their engineering and plant division under the name of D.M.M. (Machinery) Ltd.,

Saved from the scrap heap...
This large cast steel hydraulic cylinder was oversize in the bore; Brailey deposited ·012" (radius) heavy nickel on five internal diameters, thus saving an expensive casting and preventing long delay in delivery while a new casting was made. The Brailey Process can do the same for you in salving components scrapped from errors of machining or through wear.
A 32-page booklet covering this and many other applications of the process will be sent on request to responsible enquirers.
BRAILEY
REGD.
BRAILEY ELECTROPLATERS LIMITED
CHAPEL STREET · SALFORD 3 · LANCS · Tel. BLAckfriars 3341/2
B.56

"FESCOL"-ising PROTECTS RAMS AND PACKINGS



Photograph by courtesy of Messrs. BABCOCK & WILCOX LTD.

The 71 Rams used in this 8,000-tons Bending Press, the property of Messrs. BABCOCK & WILCOX LTD., have all been "FESCOL"-ised and thus rendered resistant to corrosion and the progressive effects of wear; in turn, this ensures protection for the packings on which the efficiency of a hydraulic ram depends.

EXECUTIVES *are invited to write for List E.D.2 which describes the process and indicates the wide field for application—in the protection of new and costly plant, for re-building worn parts, and for rectifying machining errors.*

FESCOL LIMITED Est. FESCOL 1920

Branch Works:-

HUDDERSFIELD, Cable Street.
PORT GLASGOW, Industrial Estate.

Sole Licensees for Australasia:-
DE HAVILLAND AIRCRAFT PTY, LTD., Milperra Rd., Bankstown, N.S.W.

NORTH ROAD LONDON N.7.
TELEPHONE · NORTH · 3025-6-7
TELEGRAMS · FESCOLDOM · PHONE · LONDON

119 Victoria Street, London, S.W.1. They represent in Great Britain the Demag A.G., Maschinenfabrik Meer A.G., Miag Fahrzeugbau G.m.b.H., and Carl Canzler.

Huntington, Heberlein & Co. Ltd., metallurgical, chemical and mechanical engineers, now wholly owned by Simon-Carves Ltd., Cheadle Heath, Stockport, will continue to operate from 114 Cromwell Road, London, S.W.7. The Board comprises Mr. R. B. Potter, chairman, Mr. J. P. V. Woolam, Managing director, and Mr. N. Hinton, director, from Simon-Carves Ltd., and Mr. R. B. Bingham and Dr. F. J. Trotter, directors, from Huntington, Heberlein & Co.

B.S.A. CAST MILLING CUTTERS.

With regard to the materials of cutting tools it would appear that the limits of efficiency have been reached with the conventional tungsten and molybdenum high speed steels. The application of surface treatments is, however, a step in the right direction to greater tool efficiency. Another way of improving overall machining efficiency is to reduce the cost of tools. This can be done in several ways but one that is of interest is the use of milling cutters produced by a casting process.

B.S.A. Tools have approached this problem from the point of view of tool-makers rather than foundrymen. Consequently the accent is on cutter design and material, and full advantage has been taken of the fact that cutters of excellent design from a cutting point of view, e.g. staggered tooth side and face types, can be produced as easily as cutters of inferior design such as straight tooth side and face cutters. In other words the maximum advantage can be taken of the latest developments in cutter design without increase in production costs such as would have to be met in the manufacture of cutters by conventional machining methods. In addition to these advantages the material used is based on a 1.3 per cent carbon, 13 per cent chromium alloy containing small amounts of tungsten and vanadium. The advantages of using this type of alloy steel, in view of the present shortages of tungsten and molybdenum is obvious. This steel possesses excellent casting properties with complete freedom from massive segregation in the cutting teeth, provided due precautions are taken and the correct casting technique is used. Figs. 1 and 2 show good and bad microstructures respectively from the teeth of similar side and face cutters. The spheroidised structure (Fig. 1) is similar to that shown by a normal hot worked 18/4/1 high speed steel; no traces of any cast structures are apparent. These cutters are capable of removing stock at a rate of at least as great as that of a standard cutter made from 18/4/1 high speed steel. It is, however, absolutely essential that cast cutters should be run with a copious supply of " soluble " type cutting fluid.

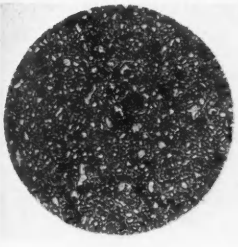


Fig. 1.
Good Microstructure.

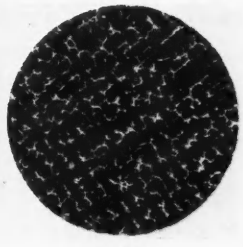


Fig. 2.
Bad Microstructure.

Fig. 3. **Group of B.S.A. finished cast cutter and rough castings.**

The nature of the pattern, the composition of the mould, the control and composition of the tool steel and the method of pouring are carefully controlled and differ greatly from normal foundry procedure. The design of the pattern, and particularly the mould, is important and needs care and attention to a number of details to achieve a sound casting, but with this attention there is virtually no tool shape which cannot be produced by this process.

Advantages of the process:

1. Full scope to design tools of maximum efficiency without the limitation effected by conventional methods of machining from the solid.
2. It is possible to produce milling cutters with alternate teeth having opposite helix angles with no more difficulty than a cutter with identical teeth.

When the technical skill and experience of Lewis of Redditch produces springs designed only for you — then 'Many Happy Returns' isn't a wish, it's a fact. And doesn't that sum up everything you can ask of a spring?

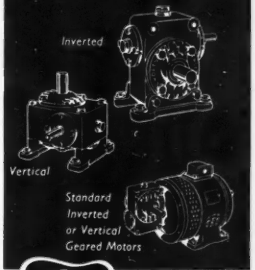
Makers of high-quality springs for 30 years. A.I.D. approved.

LEAVE IT TO Lewis OF REDDITCH

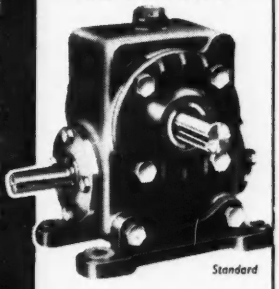
Telephone: Redditch 720/1/2

THE LEWIS SPRING CO. LTD.
RESILIENT WORKS, REDDITCH
London Office: 322 HIGH HOLBORN, W.C.1.
Telephone: HOLborn 7479 & 7470.

CROFTS
RADIATION
UNIVERSAL
MOUNTING
WORM
GEARS
FOR SMALL POWER APPLICATIONS



UNIVERSAL MOUNTING



DELIVERY FROM
STOCK
1⅛", 1¾", 2¼" CENTRES,
up to 2½ H.P., from 5 to 1 up to 60 to 1 Ratio. Other Ratios at short notice

Standardised main body with foot position interchangeable to make the gear unit either Standard, Inverted or Vertical.

WRITE FOR FOLDER 512

Crofts **CROFTS (ENGINEERS) LTD., BRADFORD.**
'Phone: 65251 (10 lines) 'Grams: "Crofters, Bradford."

3. Cutting teeth can be produced having any shape in any direction. It is not necessary to generate the backing or support of a tooth as one, or a series, of straight lines.
4. Cutters can be produced having ample swarf clearance and are still efficient after a number of regrinds.
5. Where a cutter has a constant axial shape and plain ends—as for example a helical slab mill with plain ends—it is possible to produce cutters of any length (within the limits of the pattern) from one standard pattern. A pattern for a 6″ long cutter would produce tools any length from ½″ up to 6″ long.
6. Where form relieved cutters are made it is possible to take advantage of the special B.S.A. Tools Ltd. surface treatments such as Golden Arrow and Blue Arrow. As the rake faces only are ground these treatments will help to prevent wear on the clearance faces.

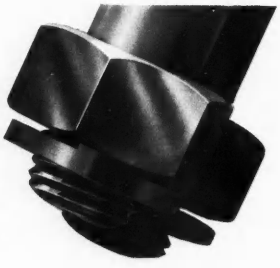
The many advantages pertaining to staggered tooth cast cutters in comparison with machined straight tooth side and face cutters, include the following :

1. Higher speeds and feeds and greater depth of cut gives heavier and faster cuts.
2. Shearing action of chip formation reduces wear on teeth, thus prolonging cutter life.
3. Less power required for similar cuts.
4. Metal can be removed at an average rate of 70 per cent greater while retaining a life equivalent to that of standard straight tooth cutters.
5. B.S.A. Cast Cutters cost 20 per cent less than list price of standard cutters.

The Industrial Diamond Information Bureau, London, E.C.1 has compiled a survey of the Diamond Tool Industry in 1950, utilising the main sources of supply of this literature. This year's report is sub-divided into the following groups :—Scientific Aspects, Diamond Radiation Counters, Ruling Diffraction Gratings, Gramophone Needles, Surface Finish, Hardness Testing, Shaped Diamond Tools, Truing of Grinding Wheels, Diamond Drawing Dies, Diamond Powder, Diamond Grinding Wheels, Glass and Quartz, Gemstone Polishing, Corundum, Diamond Drilling. Copies of this publication (11 pages mimeographed) can be obtained free of charge from the above address while the supply lasts.

The Twelfth Flying Display and Exhibition organized by the Society of British Aircraft Constructors will again be held at the Royal Aircraft Establishment at Farnborough Aerodrome, Hampshire. The Ministry of Supply has loaned Farnborough airfield to the S.B.A.C. for the duration of the Display—the 11th-16th September, 1951.

Overcome all vibration problems with



PHILIDAS self-locking nuts

(ALL SIZES & THREADS)

NEW CATALOGUE and full details from

PHILIDAS DIVISION of Whitehouse Industries Ltd.,

FERRYBRIDGE, KNOTTINGLEY, YORKS.

BRITISH STANDARDS

(Copies of British Standards may be obtained from the British Standards Institution, 24, Victoria Street, London, S.W.1.)

Internal Micrometers (including stick micrometers) (B.S. 959 : 1950). Section 1 of the revision relates to internal micrometers and contains requirements similar to those given in the previous editions of the Standard, except that a requirement for rigidity has now been included.

Section 2 relates to stick micrometers. The primary object of this section is to specify standards of accuracy, and requirements of design have been included only where design features have a direct bearing on the accuracy or use of the instrument.

Notes on the method of testing internal micrometers are included in an appendix. Price 2/-.

Classified Advertisements.

The rate for all classified advertisements is 6d. per word ; in bold print 9d. per word ; minimum order 6s. Box number advertisements 1s. extra. Instructions together with remittance must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

SITUATIONS VACANT

ADMIRALTY (CIVIL ENGINEER-IN-CHIEF'S DEPARTMENT).

Immediate vacancies exist for Architectural and Civil Engineering Assistants in the Drawing Offices at the following establishments, Pinner (N.W. London), Portsmouth District, Sheerness (Kent), Yeovilton (Somerset), Caerwent (Monmouth), Culdrose (Cornwall), Devonport (Devon), Lossiemouth (N.E. Scotland), Liverpool, Belfast, Leeds and Glasgow. In addition there are likely to be vacancies at all Admiralty Establishments in this country and Northern Ireland with opportunities for service in Admiralty Dockyards overseas.

Applicants must be competent draughtsmen and designers with experience in some of the following types of Building and Civil Engineering Structures and Works.

Structural Steelwork, Reinforced Concrete, Dock and Harbour Works, Accommodation, Residential, Office, Store and Factory Buildings, Oil Fuel Tanks and Pipe Lines, Airfield Construction and Maintenance, Rail, Road, Water sewerage and Heating Services, etc.

The salary range is £300 p.a. × £20 p.a.—£525 per annum (Consolidated London Rate) subject to Provincial Differentiation of £20 p.a. at the minimum and £30 p.a. at the maximum. The minimum is tied to age 21 with an increase (or reduction) for each year over (or under) the age of 21, up to a maximum, on entry, of seven increases. In addition appropriate rates of Foreign Service Allowances are payable at Stations abroad.

The appointments are temporary.

Applications should be made giving full particulars of experience to the Civil Engineer-in-Chief, Admiralty, Chamberlain Way, Pinner, Middlesex.

INDUSTRIAL ENGINEER, must be fully capable in rate setting, production standards, and incentive system and must have had experience in heavy industry, steel fabricating or shipbuilding plants. Give full account of training, experience and references and recent small photograph in first letter. Location Gulf Coast.—Box No. I.S.C.I.

A CHIEF ENGINEER.—Medium-sized London food manufacturing firm seeks a good "all-round" man who combines inventive capacity with practical ability to direct the men on the job. He will be responsible for plant, buildings, and essential services. Must be aged 30 to 45, have engineering degree or equivalent. Experience of food industry an advantage. Salary £700 to £1,000 according to qualifications. Write, giving age and full relevant details, including present salary, to Box No. B.C.I.

A.M.I.Mech.E., A.M.Brit.I.R.E., City & Guilds, etc., on "NO PASS—NO FEE" Terms. Over 95% successes. For details of Exams. and courses in all branches of Engineering, Building, etc., write for 176 page Handbook—FREE.—**B.I.E.T.** (Dept. 96), 17 Stratford Place, London, W.1.

MACHINERY, ETC., FOR SALE

NISSEN TYPE HUTS, ex-Government stock, reconditioned and supplied ready for erection. All sizes in 6 ft. multiples. 36 ft. by 16 ft., £71 10s. 0d. & £59 8s. 0d.; 24 ft. by 16 ft., £50 12s. 0d. & £41 16s. 0d.; 72 ft. by 16 ft., £134 4s. 0d. & £106 14s. 0d.; delivered U.K. Plasterboard huts and other buildings. Some 24 ft. span Nissens.—Write, call or telephone, **Universal Supplies (Belvedere) Ltd.,** Dept. 50, Crabtree Manorway, Belvedere, Kent. Telephone No. ERITH 2948.

MISCELLANEOUS

CLEANING, sterilising and repairing Service for Industrial Gloves, Aprons and Overalls, etc.—quick, reliable and well-recommended—**Burlington Gloves Ltd.,** Treforest Trading Estate, Glam. 'Phone : Taffs Well 152.